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BROWN BOVERI REVIEW

Electric and Diesel-Electric Traction

The new $B_0'B_0'+B_0'B_0'$ double locomotive type Ae 8/8 of the Berne–Lötschberg–Simplon Railway, Switzerland
Total weight 160 t, one-hour rating 8800 hp at 75 km/h, top speed 125 km/h

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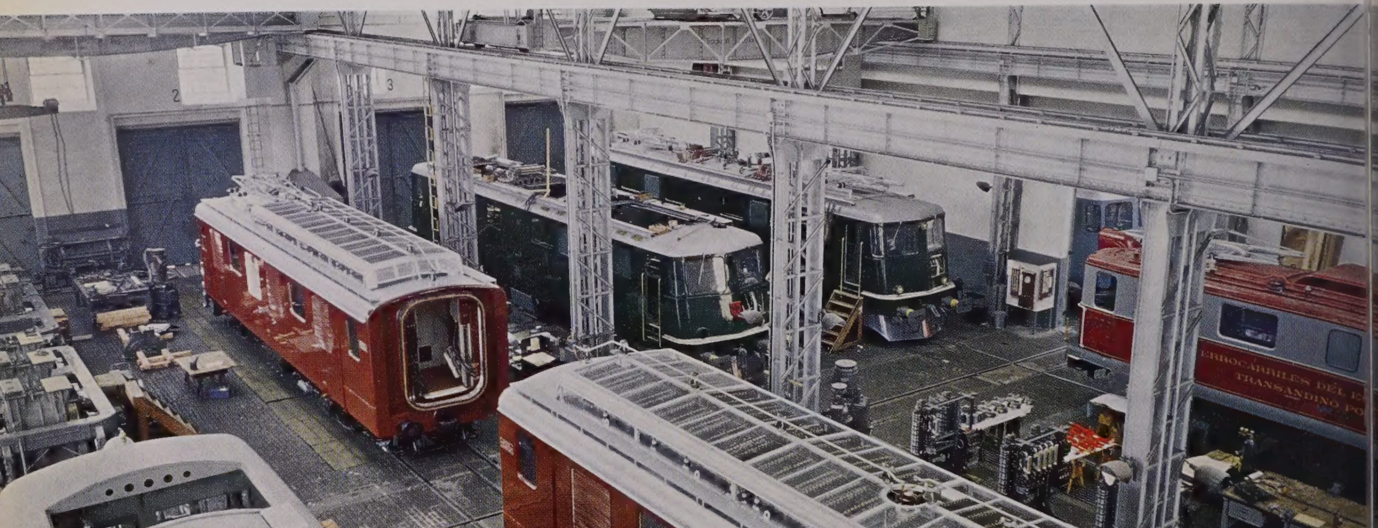

View inside the Brown Boveri locomotive erection shop at Münchenstein, Switzerland

Running diagonally across the picture from the bottom right-hand corner are the two halves of the Ae 8/8 locomotive of the Berne–Lötschberg–Simplon Railway (BLS); left, in the foreground, is the body of one of the $C_0'C_0'$ diesel-electric locomotives for the Roumanian State Railways (CFR). Right, at the rear, is one of the $B_0'B_0'$ combined rack and adhesion locomotives for the Transandine line of the Chilean State Railways. At the top of the picture are two of the well-known Ae 6/6 locomotives of the Swiss Federal Railways.

THE BROWN BOVERI REVIEW

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ELECTRIC AND DIESEL-ELECTRIC TRACTION

621.33

THE DEVOTION of particular care to the construction of traction vehicles is a long-standing Brown Boveri principle. The well-known pioneer achievements—complete vehicles and such parts as traction motors, airblast circuit-breakers and tap changers, to mention but a few—provide the stimulus and, as ever, the obligation to foster the Company's own techniques and break new ground. Above all, this involves comprehensive development work and the performance of very exacting experiments. While endeavouring to utilize modern elements and principles on the one hand, in order to keep in the forefront of technical progress, the special requirements of the traction field regarding weight, space and robustness must also be taken into account. In this respect the Company strives to provide the transport undertakings with only reliable and economical vehicles.

The present issue of this journal first deals with some of the many interesting new designs in this field. Subsequent articles compare the most important traction systems—a.c. at $16\frac{2}{3}$ or 50 c/s, multi-system and diesel-electric traction—with reference to a number of modern vehicles. Following an account of the various applications of d.c. systems for local and suburban traffic, there are three articles dealing with special subjects, namely air-conditioning, rack railways and automatic control of aerial ropeways and funiculars.

Traction motors and direct drives are traditional Brown Boveri specialities. Comparisons and ideas for further development indicate the fierceness of the struggle for technical progress and the fundamental importance of suitably utilizing new materials and their properties.

The high-voltage tap changer for use on a.c. locomotives has asserted itself in the last few years, both in Europe and overseas. A detailed description goes into the principles and design of this unit and the latest version of it for 25 kV. Closely associated with the switchgear is the problem of control, to which a separate article is devoted.

Pantograph current collectors for high speeds enable rail vehicles to meet the steady demand for increased speeds. The article devoted to this subject gives some idea of the extent to which such individual elements can and must be improved to a standard compatible with modern materials by means of comprehensive experiments. Speeds of 160 km/h or more are now well within the range to which the engineer must devote more and more attention.

A completely different sphere is covered by an article dealing with curved resistance elements, which shows how the design of a single component can simplify the work of designing the vehicle.

Although the supply of individual items of equipment attracts a ready market, it is the conception, calculation, design and subsequent construction of complete traction vehicles which gives the engineer and the Company the most reward, and forms the basis for further progress. Hence the description of the new locomotives for single-phase supply at 16⅔ c/s will attract particular interest. Apart from the articulated twin locomotive of the BLS,[1] with a rating of 8000 hp, the new motor coaches of the SBB,[2] SOB[3] and BT,[4] in which, for the first time, motors with a total output of 2800 hp have been mounted below the floor, are sure to attract attention. This has been a major advance towards perfection of the 16⅔-c/s lines and proves that there is still plenty of room for progress with this supply system.

50-c/s and multi-system traction affords an opportunity for a historical comparison, in the course of which the reasons for the success of 50-c/s traction are investigated. Enquiries for vehicles operating at normal mains frequency are normally handled by a syndicate in which firms of repute, specializing in the electrical and mechanical parts, co-operate. Evidence of the fruitful results of this co-operation is provided by numerous locomotives and motor-coaches supplied to overseas railways.

D.C. multiple stock of the Centovalli Railway (Switzerland), the Barcelona Underground and the Spanish State Railways (RENFE) is described in detail. In addition to these, other transport vehicles for local services, such as trams and trolleybuses, for which Brown Boveri have supplied the electrical equipment, are mentioned, with particular reference to the increasingly popular articulated system of construction.

Diesel-electric traction continually exhibits new, technically interesting aspects. Especially in this field the Company is on the point of realizing some new solutions, and rejoices in the success of the co-operation with concessionaires and licensees, which in this case is most intensive.

It is apparently not universally known that Brown Boveri have for many years dealt with air-conditioning in traction vehicles and complete trains. This special sphere will gain importance with the steadily increasing demands for passenger comfort.

The economic boost that renewal of the vehicle park can bring about has been experienced by rack railways. Brown Boveri have consolidated and expanded their position in this field by supplying a variety of important vehicles. Just as reliably as the rack railways, funiculars and ropeways equipped by the Company with electrical gear are carrying more and more passengers safely and rapidly to their destinations. The provision of newly conceived drives enables the ropeways to operate more economically.

Automation, which in the present issue is only dealt with insofar as it concerns the control of vehicles and the operation of aerial ropeways, is nevertheless entering other traction fields to an increasing extent. Traction vehicle construction is in the middle of a phase in its evolution which will bring about far-reaching and fundamental changes. If industry is allowed to gain practical experience from comprehensive experiments in actual traction service, and is given the chance to develop their prototypes into mature units suitable for batch production, this will primarily be the reward for open-mindedness on the part of the railway authorities. At this opportunity, thanks may be expressed to all those directors and administrative bodies who help to promote technical progress and improvement by their valuable co-operation.

(KME) W. A. BOHLI

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[1] BLS = Berne-Lötschberg-Simplon Railway

[2] SBB = Swiss Federal Railways

[3] SOB = Swiss South-Eastern Railway

[4] BT = Bodensee-Toggenburg Line

THE EVOLUTION OF TRACTION MOTORS AND AXLE DRIVES

621.333

Two well-proved designs of traction motors, one old and one new, are compared to illustrate the progress made in the last twenty years as regards power, weight and the susceptibility to wear. This progress is largely due to advances in the technology of materials, in particular insulation, where numerous excellent products have been brought out. From the constructional aspect this is joined by the improved utilization of all materials, a typical case being the reduction in weight effected by welded fabrications. Recently the rectifier-fed motor for traction systems employing alternating current at industrial frequency has attracted considerable attention. Brown Boveri have also achieved notable successes in this sphere with designs of pulsating-current motors for high and medium outputs. The article concludes with reference to two new axle drive systems, in which abundant use is made of flexible elements containing rubber.

The Problems

THE CONSTRUCTION of traction motors sets out to attain a two-fold objective: Firstly, motors with a marked increase in output have to be produced at lower cost, occupying less space and weighing less. In addition, they have to run for longer periods without attention and without breakdown, thereby reducing maintenance costs.

Although development of traction motors has not been quite so tempestuous as in other branches of electrical engineering, a number of important successes have nevertheless been gained. But new ideas and knowledge, as well as new stipulations by the railway companies, are continually being forced on the designer and posing new questions and problems. Modern methods of calculation and experimental investigation, a wealth of experience, and the latest achievements of material technology and manufacturing techniques have smoothed the way to better and more efficient machines. A complete review of present-day practice would exceed the scope of this article. It will therefore deal only briefly with a few selected topics.

Progress in the Design of Single-Phase Series Motors

The present discussion may be opened by comparing the data of two single-phase motors which, although separated by about twenty years, both attracted great attention in Switzerland. The first is the motor built in 1929/30 for the Ae 4/7 locomotives of the Swiss Federal Railways, and the new type, built in 1951/2, with which the majority of the Ae 6/6 locomotive are equipped. The Table on page 542 shows the principal data of both motors.

The choice of the older motor dated 1929/30, as the basis of comparison, was made for a very good reason. Its design immediately follows the period of resistance connectors, split interpoles and uncompensated armature fields, when the principles which are now standard practice were just beginning to enter the field. Thus the comparison between the modern system and what was then an advanced design is particularly attractive.

The increase of nearly 20% in the output of the new motor may at first appear somewhat modest. It is governed solely by the haulage duties of the Ae 6/6, for which it suffices completely. The top speed of 75 km/h stipulated for the mountainous routes and governing the one-hour rating of the motor, also the permissible axle pressure of 20 t and the adhesion values gained by experience, render the incorporation of higher-powered motors superfluous. More recent studies have, however, proved that the power-weight ratio of the motors can be appreciably increased for locomotives primarily engaged on high-speed traffic on flat routes. As may be gathered from the Table, the main reason for the increased output is the higher speed of the motor. Since the diameter of the driving wheels of the Ae 6/6 locomotive is

Year		1929/30	1951/52
Rated voltage	V	395	390
Output, one-hour/continuous	kW	610/590	735/660
Current, one-hour/continuous	A	1820/1750	2120/1900
Speed at one-hour and continuous load	rev/min	550/565	820/875
Maximum speed	rev/min	850	1380
Torque at one-hour output	mkg	1080	920
Starting current	A	2300	3020
Diameter of driving wheels	mm	1610	1260
Gear ratio		1:2·57	1:2·56
Weight of motor	kg	6700	3850
Number of poles		16	14
Rotor: diameter and iron length l	mm	1043·5; 412	930; 280
Rotor slots: number and dimensions	mm	184; 7·8 × 29	133; 10·6 × 31
Rotor slots: number and arrangement of conductors		2 × 3	2 × 2 × 2
Commutator: diameter and contact surface	mm	850; 257	650; 208
Maximum peripheral speed of commutator v	m/s	38	47
Number of brushes, dimensions	mm	5; 13 × 44	4; 11/2 × 50
Current per peripheral unit length A at one-hour load	A/cm	383	552
Main-pole flux at one-hour load	Mx	$3{\cdot}6.10^{6}$	$2{\cdot}47.10^{6}$
Induced voltage	V	3·8	2·6
Commutation factor $k = A{\cdot}v{\cdot}l\left(1 + \frac{h}{b}\right)$	Acm/s	$2{\cdot}23.10^{8}$	$2{\cdot}42.10^{8}$

much smaller than that of the Ae 4/7, the tractive effort at the wheel rim, referred to one axle, is about 7% higher, despite the lower torque of the motor.

An impressive feature is the difference in weight between the two motors. The main reason for this is that the more powerful new motor is smaller in diameter and in the length of its active iron. Owing to its smaller number of poles, however, the pole pitch and relative arc are the same as in the older machine. On the other hand, the main pole flux of the new machine is much smaller on account of the shorter iron. Consequently the voltage induced in the winding by transformer action in the neutral zone is reduced from 3·8 to 2·6 V. The object of reducing this transformation voltage originates from the view that it exerts a marked influence on the overload capacity of the motor and the life of the brushes and commutator. It would be out of place, however, to attempt to lay down generally valid limits for this. Different assumptions can be made, depending on the main purpose which the motor will serve, i.e. whether it is used for long-distance express traffic, or for local or goods traffic. In consequence, the designer of the traction motor cannot possibly know too much regarding the type of railway duty visualized, and its peculiarities.

Naturally the reduction allowed for the pole flux and transformation voltage has to be recovered somewhere else. In the present case this is done by a marked increase in the rotor current, by raising the number of conductors per pair of poles, and by increasing the current per conductor and the current density. Admittedly this causes the copper losses to grow, apart from rendering commutation more difficult. The former can be taken into account by a number of measures. Firstly the temperature rise is permitted to approach more nearly to the internationally agreed limits. Then the arrangement of the rotor conductors in four layers, each of two bars, reduces the supplementary losses, the temperature distribution across the cross-section of the slot being more uniform than the arrangement with two layers of several conductors.

To obtain an approximate assessment of the commutation conditions, we make use of the commutation factor k, which is the product of the current density per peripheral unit length, the peripheral speed and iron length of the rotor, and the expression

$(1 + h/b)$ containing the ratio of the depth to the width of the slots. The Table opposite also gives the values of this factor, from which it may be observed that, despite the heavier current and peripheral speed, there is no great deterioration. A favourable influence was exerted on the new motors by the shorter iron length and the broader slots.

The last ten years have brought the electrical industry some valuable means of improving commutation. The most prominent of these is the system of twin brushes, which has been widely adopted in the field of a.c. traction motors on account of its good behaviour. But considerable progress has been made in the properties of brush materials in general. The Table shows that the specific current loading has been almost doubled since 1930, but to be fair it must be stressed that the improvements in the design of the brush-holders are partly responsible for this. Motor manufacturers, railway experts and brush producers have made considerable efforts to find methods which, despite the compact design, permit rapid replacement, provide a brush pressure unaffected by the state of wear and distribute this pressure evenly between the pair of brushes, under all circumstances. Another welcome feature is the means of damping the vibration of the pressure finger, provided in certain designs.

The testing stations are also making greater efforts to achieve optimum commutation conditions. Whereas previously oscillographic records were only stipulated in exceptional cases, it is now quite common practice to resort to the oscillograph especially

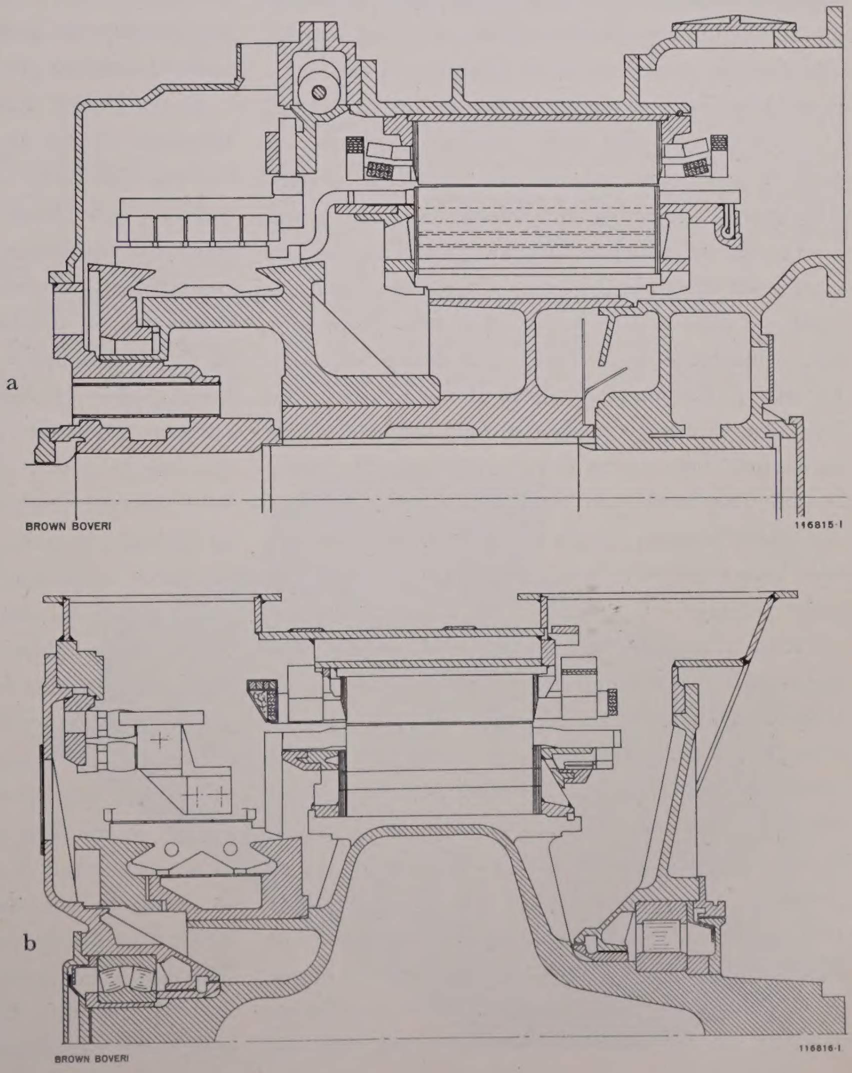

Fig. 1. – Half-sections through single-phase traction motors of earlier design and the modern counterpart

a: Motor built in 1930, rated 610 kW at 550 rev/min, weight 6700 kg.

b: Motor built in 1952, rated 735 kW at 820 rev/min, weight 3850 kg.

The appreciable reduction in weight, despite the increased output, is due not only to the higher speed and smaller dimensions of the motor, but also to a detailed study of all possible ways of saving weight.

for the prototypes, in order to check and adjust the compensation of the transformation voltage according to the field voltage curve. For the adjustment of braking circuits and for studying transient phenomena, increasing use is made of modern methods of investigation.

The fruits of these efforts could not be illustrated better than by comparing the numbers of running hours which the respective commutators achieved. Whereas the commutators of the motors built in 1930 averaged about 150 000 km before they had to be machined down, the latest commutators have already run over 1 200 000 km without requiring any machining.

The previously mentioned differences in dimensions are, however, not the sole explanation for the appreciable difference in weight between the two types of machine. It is largely the result of taking advantage of every possible means of saving weight. The progress achieved can be judged from the longitudinal half-sections shown in Fig. 1a and b. Instead of the solid cast-steel body, the new motor has a welded fabrication of carefully planned design. The heavy, projecting end-shields have also given way to lighter patterns. Much is gained by the original rotor design in the form of a hollow, flexurally rigid and distortionless body, which likewise permits the commutator to be easily and neatly attached. In spite of the heavier current it has to carry, the latter has a shorter contact surface. But even with such small items as the brush-holders and rockers a considerable saving in weight has been effected. The plain bearings, which are so prone to wear out, have been replaced by non-wearing grease-lubricated roller bearings.

Closer attention is nowadays paid to the unimpaired dissipation of heat by expedient ventilation. Distribution of the air between the various flow passages in accordance with the local demand for cooling should be aimed at in every case. By suitable shaping, especially by eliminating constrictions, sharp edges and abrupt changes in cross-section or direction, the pressure losses can be appreciably reduced, and with them the capacity and dimensions of the ventilation equipment. In the modern motor as tabulated, systematic revision of the ventilation problem on the basis of results obtained with the prototype allowed the intake pressure to be reduced by about 25%.

Motors for Pulsating Current

To the same extent as the rectifier locomotives have asserted themselves, the importance of the motor running on pulsating direct current has also grown considerably. Its design has to take into account the harmonic content of the rectified current. There are two ways of doing this. The first yields a design similar to the single-phase motor, with a completely laminated magnetic circuit. To reduce pulsation of the field, a resistance is connected in parallel with the exciter winding; this resistance then carries the majority of the current harmonics. The laminated iron causes the commutating field to exactly follow all changes in current without any time-lag. As a rule such motors only require very small smoothing chokes, if at all.

In the second method the ripple is reduced to a tolerable degree by means of special smoothing chokes. The motor in this case can be built like an ordinary d.c. motor with a small number of poles, solid yoke and laminated poles. Numerous trials have unanimously proved that, despite the pulsating component of the excitation current, the main field of these machines contains a minimum of ripple, because every change of field is damped by the eddy currents produced in the solid yoke. This damping, however, is rather unwelcome to the commutating field, because it ought to follow the change in current as faithfully as possible. Brown Boveri have allowed for these conditions by arranging that, while the main flux flows through the solid yoke, the commutating flux flows through the laminated shunt path. This is done by specially shaping the core of the main poles, as can be seen in Fig. 2. The core of the interpole is separated from the yoke by a barrier of non-magnetic material.

One of the first and most prominent examples of the new series of rectifier motors is the one built in 1958 for the dual-frequency locomotives No. 20103/4 of the French National Railways (SNCF). This has a one-hour rating of 1900 kW at 850 V and 585 rev/min. Its top speed is 750 rev/min, at which the peripheral speed of the commutator is

52 m/s. Fig. 3 shows the bogie with the motor, designed as a sixteen-pole, compensated and separately ventilated series machine. The rotor has a Latour winding laid in open slots, affording excellent commutation properties. The coil insulation conforms to class F, while the Teflon insulation of the individual conductors satisfies class H. The commutator is equipped with twin brushes. Ready for erection, the motor weighs 6800 kg: its power-weight ratio of roughly 0·28 kW/kg may be considered extremely good.

The motor is mounted in a single-motor bogie, the two axles of which are driven through gearing and Cardan shaft of the Jacquemin type. The inherently strong and rigid body of the motor acts as the cross-member of the bogie.

Practical experience has proved the expediency of the selected design. Even the severest overloads produced by exaggerated starting tests were perfectly handled by the commutating system.

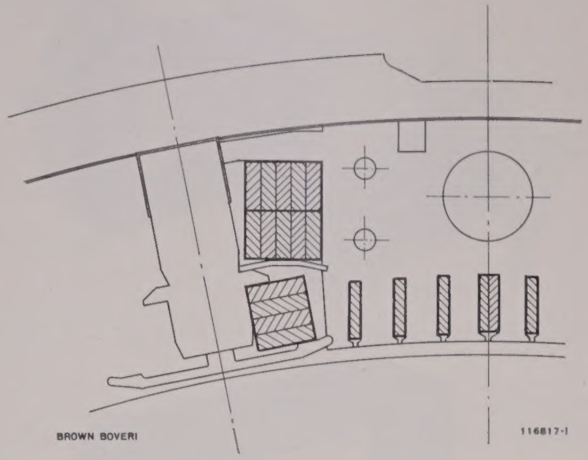

Fig. 2. – Cross-section through adjacent main pole and interpole of a rectifier-fed d.c. (pulsating-current) motor in a locomotive

The bodies of both poles are of electrical sheet. Whereas the magnetic flux of the main poles flows through the solid yoke, the flux of the interpole mainly chooses the laminated elongations of the main pole.

Contemporary Problems of Traction Motor Design

From the abundant selection of contemporary problems, that of insulation techniques may be picked out as one of the most important. Beginning in 1945, the industries concerned brought out a number of new, interesting insulating materials. The ones which particularly interest the motor manufacturers are those with a high resistance to heat, coupled with good mechanical and electrical properties.

Products containing glass fibre—first in conjunction with conventional impregnating media—were already being used at an early stage in traction

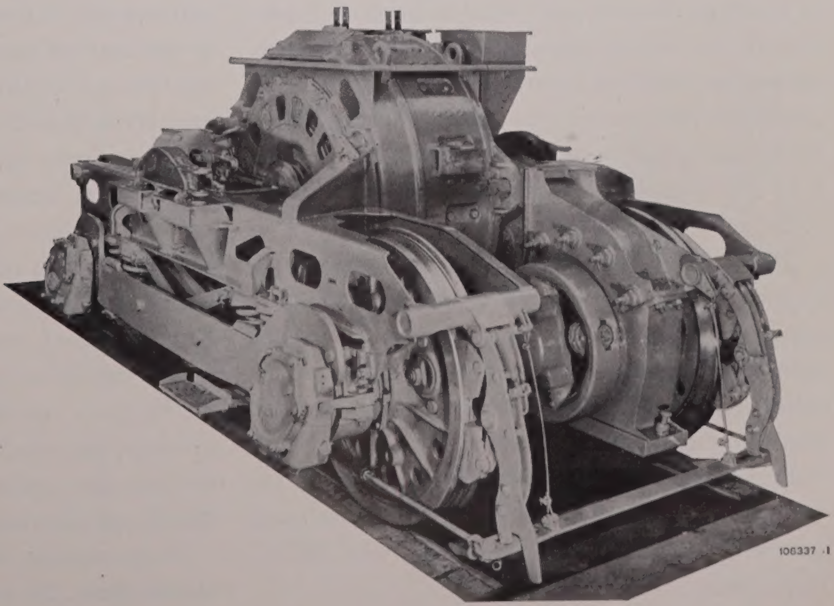

Fig. 3. – Pulsating-current motor in a single-motor bogie of the Jacquemin/SNCF design, in which it acts as the main cross-member

One-hour rating 1900 kW at 850 V and 585 rev/min. The bogie is one of those delivered for dual-frequency locomotives of the SNCF.

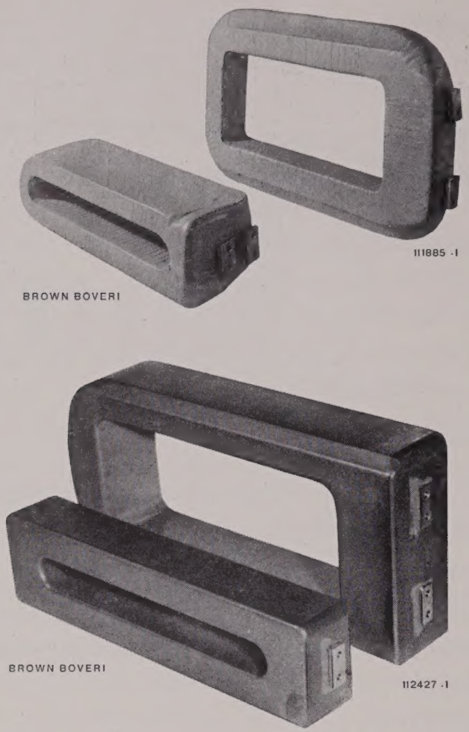

Fig. 4. – Main and interpole coils of modern design for d.c. traction motors

Top: coils with glass-fibre fabric wrapping impregnated with polyester resin. Below: moulded resin type. Both methods produce extremely solid coils with a smooth surface. During the vacuum treatment the resin penetrates right into the heart of the coil and fills all spaces between turns.

motors. Later Teflon came on the scene and attracted great attention owing to its thin application and its excellent thermal and electrical properties, particularly for the insulation of individual conductors. Teflon has rendered first-class service in a number of traction motors for several years. Its main drawback, apart from a certain sensitivity to pressure, is its poor wettability, which makes the penetration of the impregnating media very difficult.

Today, in addition to the modern impregnating varnishes, exhibiting a high resistance to temperature, there are also correspondingly impregnated glass-fibre materials, with and without mica. It is thus possible to run the machines at higher temperatures without adversely affecting their life, thus utilizing their capacity better. For this purpose the two new insulation classes F and H were introduced, permitting temperature limits of 150 and 180 °C, respectively.

To take full advantage of the load capacity of the motor as permitted by modern insulating materials, it is necessary for the design of the latter to incorporate components fully capable of withstanding local temperature conditions on the one hand, yet facilitating the dissipation of heat on the other. With the increase in the temperatures, the resistance of the winding and the losses due to heat also increase. If the dissipation of this heat were insufficient, the limiting temperature would be reached prematurely and the anticipated increase in power would not be obtained. Air pockets are the worst heat barriers in windings. To eliminate these is the object of impregnation which, by applying vacuum and pressure in the correct sequence and with the right temperature and duration of treatment, lead to complete success. It is, of course, important for the insulation and impregnating medium to be adapted to one another so that a compact compound is formed, filling all spaces.

Brown Boveri have gathered experience with several materials and impregnating media. For several years the pole coils of d.c. traction motors have chiefly been insulated with glass-fibre tape and impregnated in vacuum with polyester resin. In those cases where the voltage makes it necessary, glass tape whose electric strength is enhanced by the inclusion of mica splittings is used. As may be seen from Fig. 4, such coils are compact units with a smooth surface, rendering them insensitive to dust and moisture. A notable feature is that coils produced by this method have a temperature rise of 15–20 °C less than coils of the former design. Excellent experimental results and, in some cases, operational experience have been gained with combinations of glass-fibre fabrics impregnated with epoxy and polyurethane resins. The lower part of Fig. 4 shows a moulded resin coil of this kind, large numbers of which are incorporated in tram motors of the Vienna City Transport, where they have already been in service throughout one winter without the least signs of change or cracks. Since the coils are moulded in vacuo, the resin is able to penetrate into the spaces between the conductors and fill them completely. That is why the temperature rise of these coils is so low.

Close attention was also paid to the class H insulation. Here the main interest is concentrated on glass-fibre products impregnated with silicones and silicone impregnating varnishes. Fig. 5 shows the rotor of a two-pole trolleybus motor with silicone insulation. On account of the width of the coils and the large number of relatively thin conductors, this insulation problem gave rise to a number of special questions, which were nevertheless satisfactorily solved. A factor which tends to stand in the way of the wider distribution of this insulation in motors is the high price of the materials.

A factor which must not be overlooked is that the change to class H insulation poses a number of additional problems for the designer. First of all the fatigue strength of the soldered joints at the prevailing temperatures must be assured. Fortunately suitable products have lately come on the market, possessing a sufficiently high melting point. Furthermore, the segments and insulation of the commutator must also be taken into account. The traction subcommittee of IEC has indeed decided to adhere to the existing limits for the temperature rise of the commutator. But since silicones are cured at 200–250 °C, the commutator is subjected to these temperatures, at least temporarily. In addition, care must be taken not to overheat it by the flow of heat from the hot rotor winding. Hence the dissipation of heat demands special study. Vane connectors between the rotor winding and the commutator therefore offer far better conditions than direct soldering into elongations of the segments.

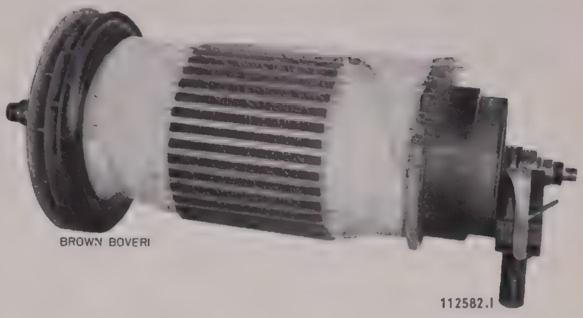

Fig. 5. – Rotor of a trolleybus motor supplied to the Lausanne Tramways

The individual conductors and the complete coils are insulated with glass fibre and silicone, and impregnated with a silicone varnish.

The fact that, in connection with these problems, the choice of brushes, lubrication of the bearings and bearing clearance again became very topical, may be mentioned in passing.

Axle Drives

Although by its very nature, the axle drive, as the element connecting the traction motor with the driving axle, belongs to the mechanical equipment, it has nevertheless repeatedly attracted the attention of the electrical engineer. With the Buchli, the spring and the disc drives, Brown Boveri have made noteworthy contributions to the solution of this problem.

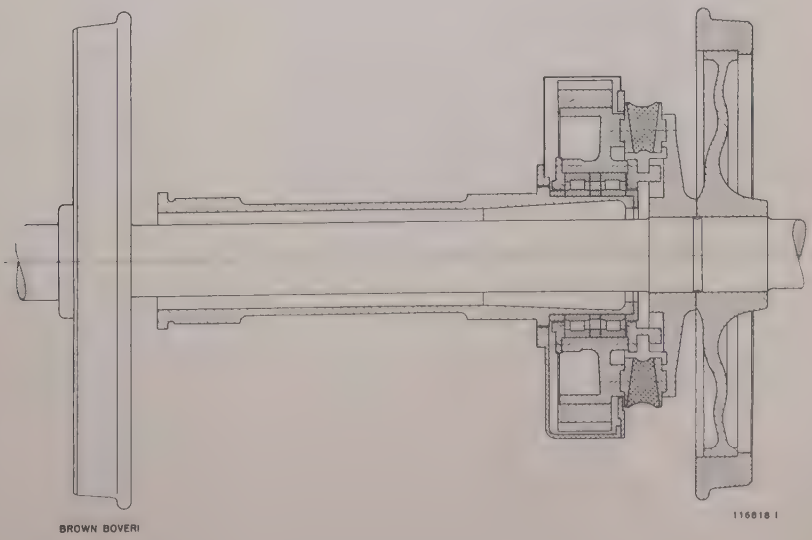

Fig. 6. – Axle drive using wedge-shaped rubber elements

The rubber elements link the main gearwheel with the carrier plate of the wheel-axle. This system is employed on the single-phase motor-coaches ET 26001–4 of the Federal German Railway.

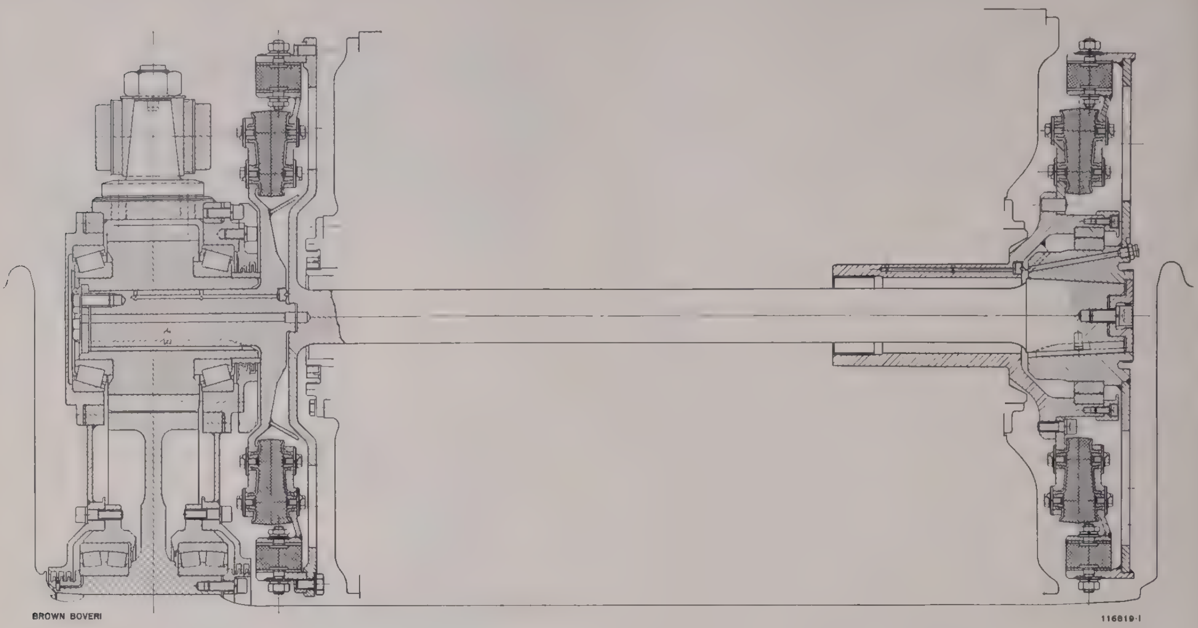

Fig. 7. – Axle drive with rubber elements between the traction motor and the gear pinion

The arrangement is similar to that of the Brown Boveri disc drive; however, the sprung steel plates are replaced by two rings of rubber sectors and segments. This system has been fitted experimentally to a single-phase motor coach type BFe 4/4 of the Swiss Federal Railways.

The increasing use of rubber in the construction of vehicles, where its elastic, shock-absorbing properties are particularly welcome, may be the reason behind the idea of using it for the axle drive too. Indeed a number of proposals have already been made in this direction, and in Germany a number of solutions of this kind have been adopted on quite a wide scale. The advantage claimed is that it completely eliminates the need for maintenance.

Although the spring and disc drives both require very little attention, the use of rubber elements has been studied for both systems, and has been put into practice.

The system shown in Fig. 6, derived from the spring drive, was developed by Brown Boveri, Mannheim for a series of converted a.c. motor-coaches of the Federal German Railway and has been in regular service since 1958. The one-hour power per axle is 290 kW, with wheels 1100 mm in diameter and with a gear ratio of 1:3·04. The design of the transmission is clearly illustrated. The metal fittings vulcanized to a ring of rubber segments are bolted to a carrier plate shrunk on the axle, on the one hand, and bolted to the main gearwheel on the other. As with the spring drive, the latter is free to rotate on a hollow half-shaft and engages with the motor pinion.

A short time after this system, a rubber transmission related to the disc drive was developed in Baden, the design of which is illustrated in Fig. 7. Instead of the two sprung steel plates, a combination of rubber sectors and segments is provided on either side, which give the transmission the desired amount of tangential and axial elasticity. The elements of the transmission are centred by curved guide rings. Emergency dogs ensure that the motor continues to transmit power to the driving axles, even if the rubber becomes defective. Since the rubber coupling is situated on the motor side of the gear, the forces to be transmitted are smaller. Nevertheless the elements have to be carefully balanced on account of the high speeds.

Four such transmissions have been fitted since the beginning of the year in BFe 4/4 a.c. motor-coaches of the Swiss Federal Railways, where they have to transmit a one-hour output of 303 kW each, and a torque of 222 mkg. When starting, the latter can even rise to 425 mkg. Experience gained so far promises a good performance in service. However, much more testing will be necessary before any real claims can be made regarding the system's qualities and advantages.

(KME) A. FEHR

HIGH-VOLTAGE TAP CHANGERS FOR A.C. LOCOMOTIVES

621.316.543.3:621.335.2.025

In 1931 Brown Boveri introduced the idea of controlling the voltage on the h.v. side of locomotive transformers and have since applied this system with notable success. The present article describes the progressive evolution of tap changers for 15 kV. Making careful use of the experience so gained, a new tap changer has now been developed for 25 kV.

The 15-kV Tap Changers

ON HIGH-POWERED a.c. locomotives the currents on the low-voltage side of the transformer are very heavy indeed. The most suitable voltage for single-phase traction motors is somewhere between 400 and 500 V.

In 1931 a project for a heavy express and goods locomotive provided Brown Boveri with an opportunity of carrying out exhaustive research into the possibilities of reducing the outlay for switchgear needed to control the secondary voltage. For a locomotive with a rating of 8000 hp, the then conventional method of controlling the voltage on the l.v. side, and the standard of switchgear available at that time, led to switchgear weighing several tons. The outcome of this study was that, for the first time, the control winding was changed over to the h.v. side of the transformer and a suitable tap changer devised (Fig. 1).

In line with the standard practice adopted with stationary tap-changing transformers, the tap selector with its contact system operating at zero current was incorporated in the transformer tank. The load switches, which have to switch the starting and motoring currents over to a diverter resistor at the momentary voltage differences between two tappings, are air-break contactors. The load switches and selector are actuated in automatic sequence by a common shaft driven by a d.c. motor.

This first model of a high-voltage tap changer brought about a reduction of roughly 4 tons in the weight of the transformer (including tap changer and connecting bars). The small size of the tap changer, the elimination of diverter chokes and numerous connecting bars, apart from reducing the weight, also simplified the internal layout of the locomotive. The number of tappings was raised from 21 to 28. This, combined with the freedom in the distribution of the step voltages, greatly improved starting. As a result of these advantages, the system of high-voltage tap-changer control, as first conceived, was adopted not only for heavy, but also for medium locomotives. About 50 vehicles were equipped with this tap changer and are still in service.

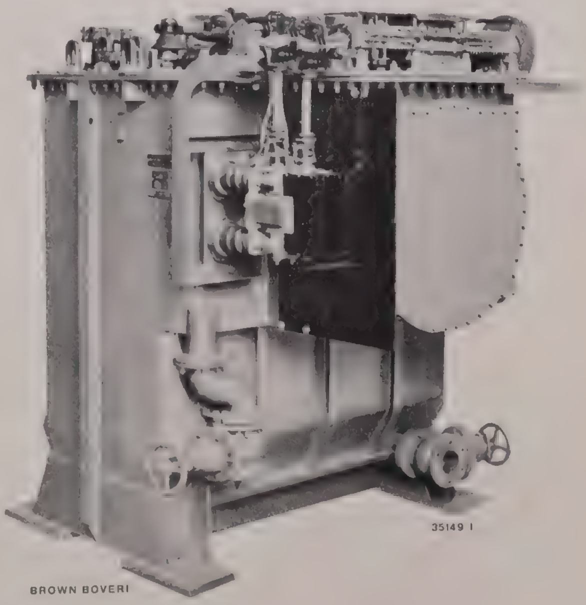

Fig. 1. – The first high-voltage tap changer built for use on locomotives

The selector is housed in the transformer tank.

Rated voltage	15 kV
Rated current	250 A
Number of tappings	28

Operational weight, including enlarged tank, about 1200 kg.

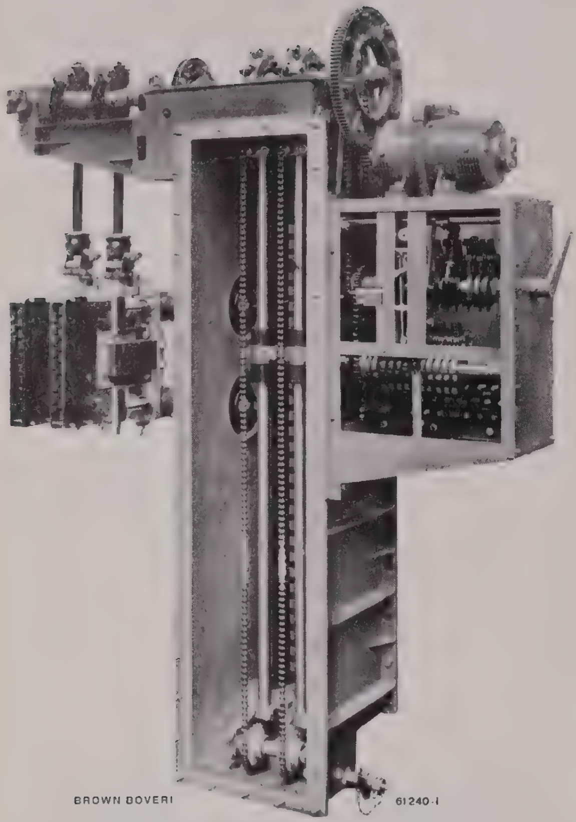

Fig. 2. – High-voltage tap changer designed as a constructional unit with 28 tappings

Longitudinal selector with leading and trailing contacts in a light-metal casing

Rated voltage	15 kV
Rated current	250 A
Operational weight	670 kg

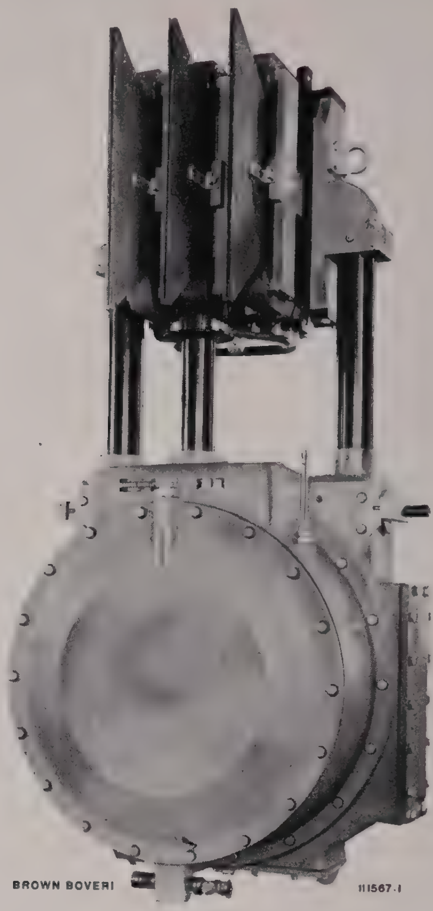

Fig. 3. – The new high-voltage tap changer

The long insulating columns supporting the load switches are evidence of the high insulation level.

Rated voltage	25 kV
Test voltage, 50 c/s	75 kV
Rated current	400 A
Operational weight	400 kg

Another pioneer achievement in the development of electric locomotives was the incentive for a great effort to reduce the weight of the h.v. tap changer considerably. In the first B_0B_0 locomotives with an output of 4000 hp and a top speed of 125 km/h, which were planned by Brown Boveri in 1942 and which came into service in 1944, the tap changer appears in its modified form (Fig. 2). The selector was no longer in the transformer tank, but in a separate light-metal enclosure with considerably reduced oil volume. The selector and load switch, together with the drive, form an integral block. The tap changers of this design have found very wide application. Although insulated for 15 kV, 16⅔ c/s, they have also been employed in locomotives with converters, rectifiers and 50-c/s motors, running off a supply of 25 kV, 50 c/s, although the range of variation at the h.v. winding is only 15 kV.

After the war, when the need for powerful locomotives in the large, busy networks in Germany and France increased by leaps and bounds, this tap changer was backed by several years' operational experience. New studies finally led to the development of a h.v. tap changer for service voltages up to 25 kV (Fig. 3), which will now be described.

New Tap Changers for 25 kV

Development Aims

If the insulation to earth is increased to 25 kV, with a maximum service voltage of 27·5 kV, and the control winding of the locomotive transformer utilized for the full voltage range, it is then preferable for the voltage per tapping to be increased, in order to obtain the most favourable voltage graduation, in conformity with the motor characteristic. The load switches then have to cope with voltages up to 2000 V.

From the experience that these devices may be employed on locomotives of all kinds and under the widest variety of traction conditions, the number of tappings was raised from 28 to 32, and the rated current fixed at 400 A.

Locomotive tap changers have to put up with some rough treatment in their service life, performing up to 20 000 switching operations every day. Due allowance for this must be made in the design. The components must be tested with regard to their probable wear and their replacement by spare parts assured by careful consideration of the dimensions. The degree of utilization of locomotives is nowadays so high that overhauls are only carried out at long intervals; in the meantime the amount of maintenance must be as small as possible.

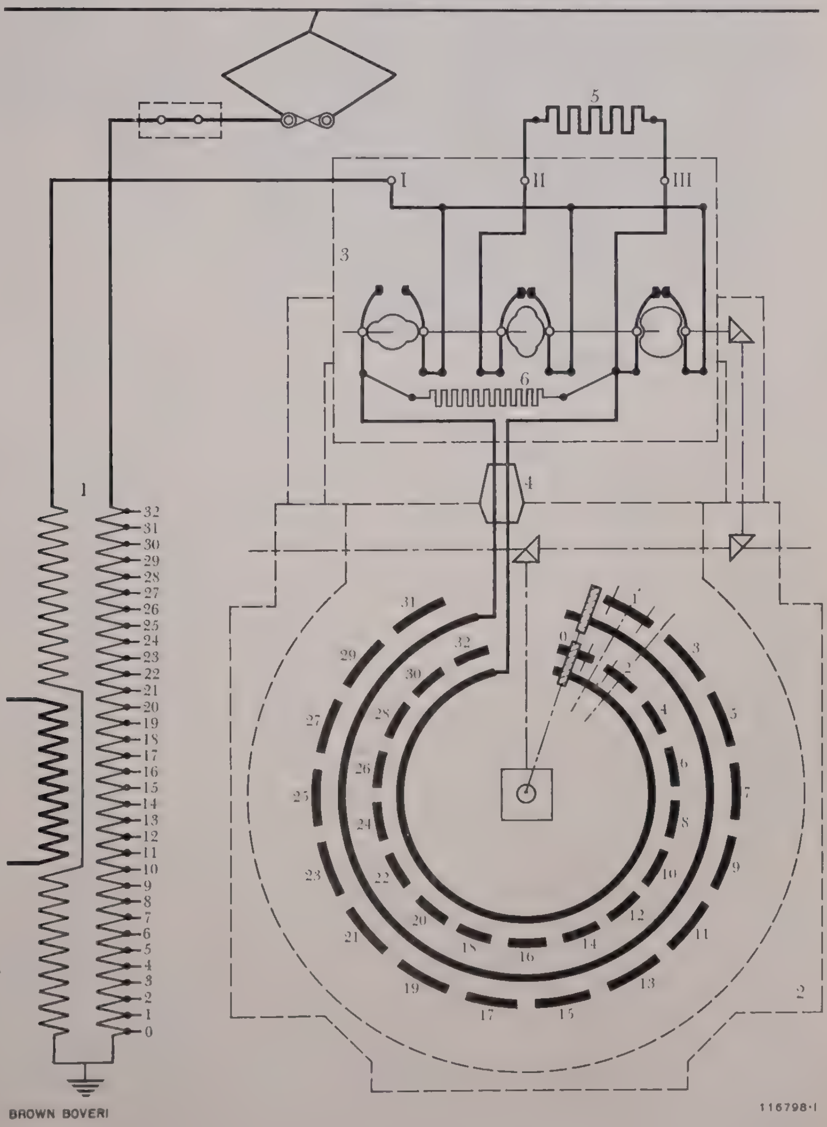

Fig. 4. – Circuit diagram of the tap changer illustrated in Fig. 3

1 = Transformer
2 = Selector
3 = Load switches
4 = Bushing
5 = Diverter resistor
6 = High discharge resistor

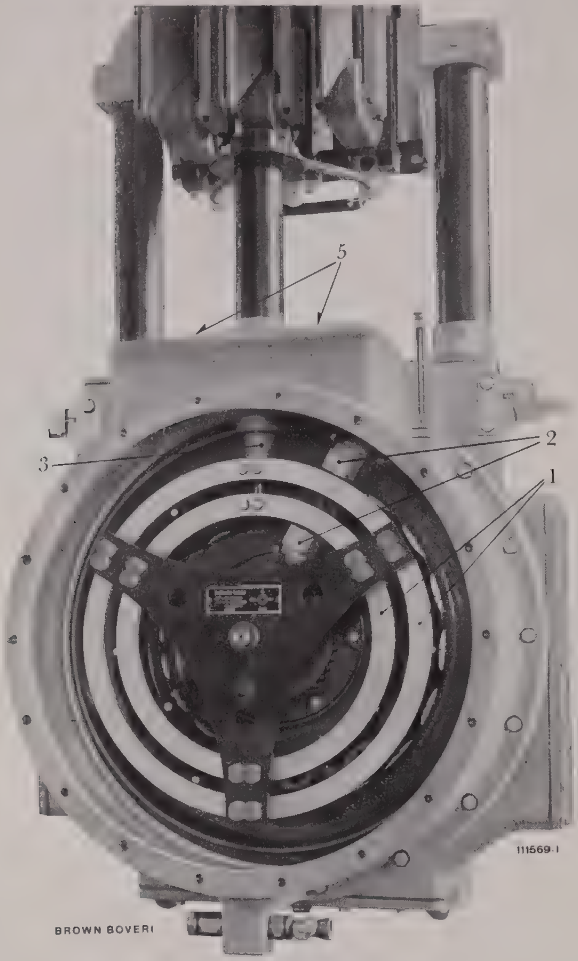

Fig. 5. – Tapping selector, open

1 = Pick-off rings
2 = Contact rollers in insulated casing
3 = Bushing
4 = Oil drain cock
5 = Safety valves

Apart from abrupt changes of temperature, which may sometimes be experienced in service, the requirements regarding the ability to withstand climatic conditions stretches from tropical climates to arctic conditions. Abnormally high atmospheric humidity and severe contamination may appear to make things more difficult.

Here too a further reduction in weight was aimed at.

Design of the Tap Changer

With these aims in view and under the conditions listed, a tap changer has been produced which, in its harmonic appearance alone, clearly differs from a scratch solution. The selector and load switch form a symmetrical entity with two free shaft extensions for the drive. The latter can be mounted on the left or the right.

As may be seen from the circuit diagram (Fig. 4), the motion of the drive shaft is transmitted through gearing at the centre of the circular selector to a pivoted arm on which are mounted contact rollers. These form the connection between the tapping contacts and the leads to the load switches. The circuit, as was chosen in this case, should not only be assessed from the electrical aspect. It does, in a way, suffer from the drawback that voltage drops are produced when the diverter resistor is first cut in on changing from one tapping to the next. In practice, however, on account of the rapidity with which the switching operation is performed, this does not have any effect on the tractive effort. With this arrangement though, the gear system is very simple, and can be designed and dimensioned for very severe continuous mechanical stresses, despite its compactness. The former system with leading and trailing contacts involves a good deal more equipment in contrast. The arrangement of a third load switch reduces the mechanical and electrical stresses of these elements and thus prolongs the period between successive overhauls.

Apart from the above considerations, the problems of the insulation also call for simplification of the selector. In view of the severity of the mechanical stresses, it is inevitable for microscopic particles to be torn from the surface of the contacts over which the tap changer rolls, and that they should then be deposited on the insulation by the action of the voltage field, the density of the deposit being governed by the nature of the surface finish, eventually forming conducting paths. This phenomenon grows with increasing service voltage and has to be allowed for in the dimensioning of the insulation and design of the live parts and the earthed poles opposite them. The oil in the selector is separated from that in the transformer tank by an insulating barrier.

Fig. 5 shows the selector with the cover removed. At the front, held in position by a three-armed holder of insulating material and fixed at the top to the bushing, are the annular pick-off leads. This allows

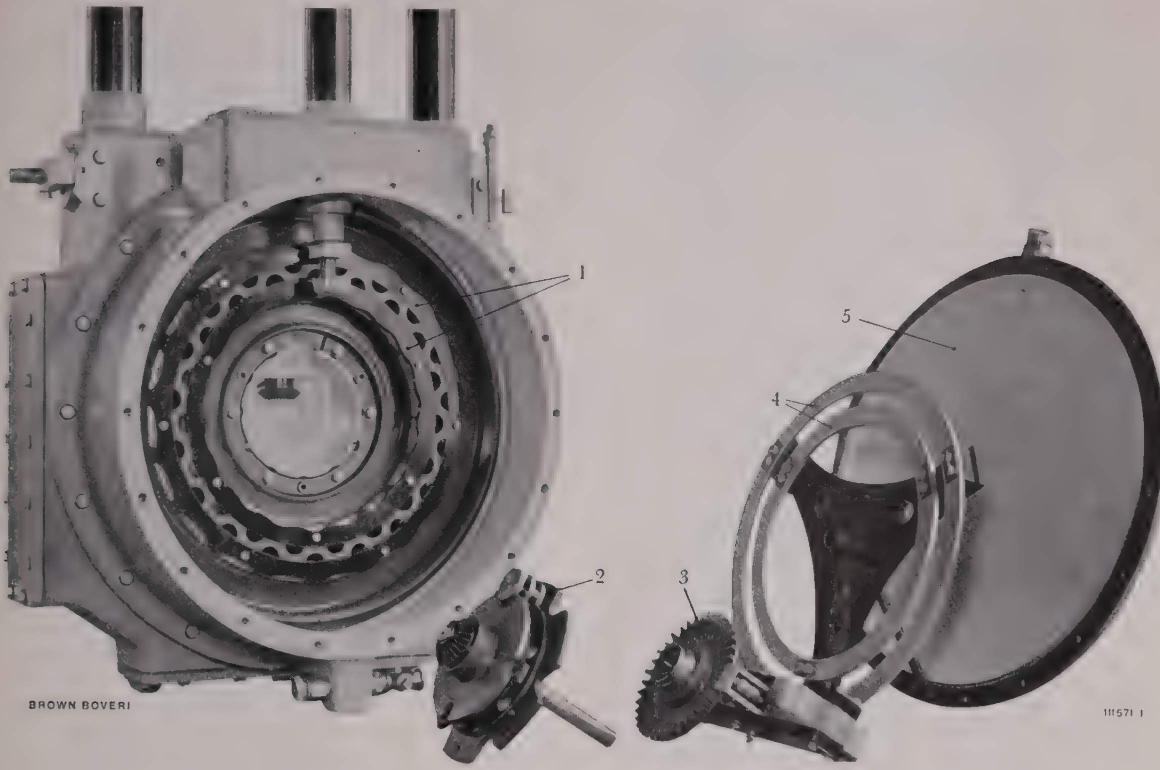

Fig. 6. – Selector, stripped for overhaul

1 = Guide rings for rollers 2 = Stepping gear 3 = Step wheel with roller contacts 4 = Pick-off rings 5 = Cover

the roller contacts and their running to be observed easily when the tap changer is being tested. Fig. 6 shows how the internals can be removed in groups when the fixing screws are released. If the guide rings are also removed, the tapping contacts are then exposed for inspection (Fig. 7). They are easily replaced. The fact that the insulating plate is of moulded resin is evidence of the intention to make the possible creepage distances between the tapping contacts, and especially between these contacts and earth, as long as possible. The insulating plate is mounted between the rear and the front parts of the casing; screw attachments, which could act as point electrodes, have been carefully avoided. The mass of the central gear system is at a medium potential.

The stepping gear is designed to act in such a manner that, when changing from one tapping to the next, the contact rollers are first advanced into a preselection position and then to the new tapping, in a second movement. If, however, several tappings have to be run through, the preselection positions are merely halting points and the rollers carry on undelayed beyond the actual tapping positions. Combined with the sinusoidal motion of the contact arm, this drive assures minimum possible wear on all components, both quantitatively and qualitatively.

Although a requirement of this nature was not included in the aims set, the switching time from one tapping to the next can be reduced from 0·5 to 0·3 s. With a transit time of 10 s for the full 32 tappings, the tap changer was subjected to 15 million operations during the endurance tests, without the least sign of wear.

Both for tap changers of stationary transformers, and for those employed in traction, it is tacitly assumed that the selector is a completely reliable piece of apparatus, and great efforts are made to attain this reliability. But the selector can also be harmed by external influences. Defects in the load switch assembly, on the connections or diverter

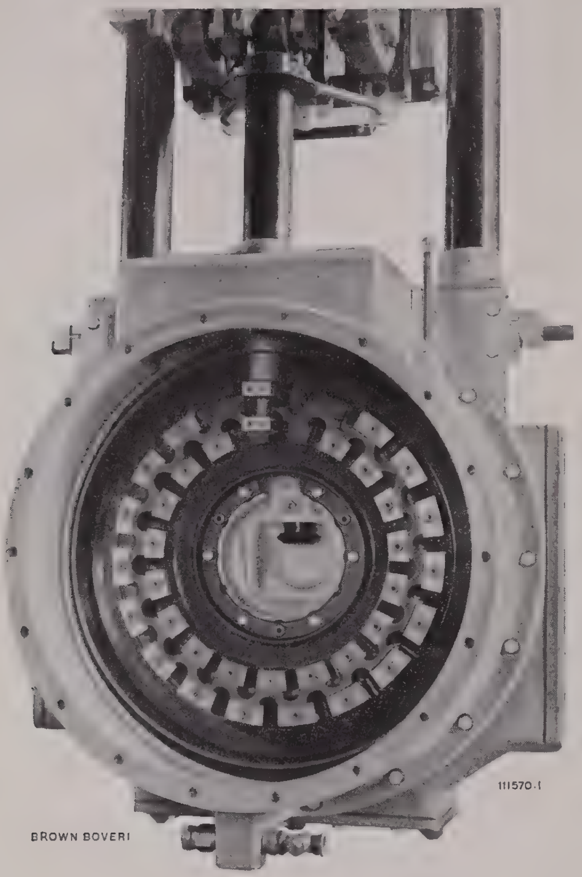

Fig. 7. – Contact plate of selector, exposed for inspection and cleaning

The contacts are easily replaced, the transformer remains filled with oil.

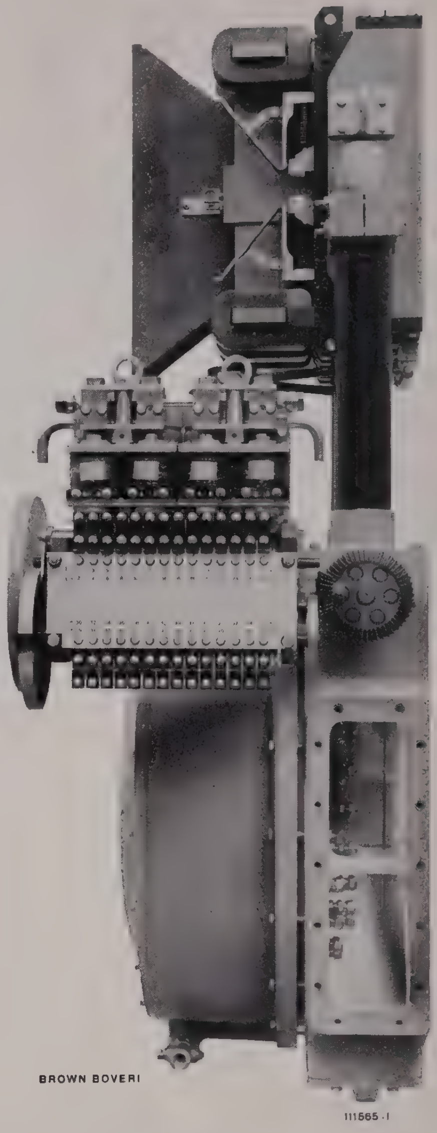

Fig. 8. – Tap changer with drive and indicator contacts

The arc chutes and magnet plate are removed from the front load switch. The cover is also removed from the bottom part of the selector casing; showing the connections to the transformer.

resistor, can lead to the production of arcs when the contact rollers run off the contacts, resulting first of all in short circuits in the tappings and finally to earth leakage, if the vehicle is not protected by a modern circuit-breaker. Even tapping shorts develop an appreciable short-circuit energy. To prevent explosion of the selector, the bushing at the top is augmented by a pair of amply dimensioned safety valves, which blow off as soon as the pressure becomes intolerably high.

These considerations regarding the reliability of the selector have led to a very carefully planned design for the load switch assembly. This comprises contactors actuated by cams. They are interlocked with one another and with the selector gear. The switching rate mentioned above, which is perfectly feasible from the mechanical aspect, assumes that the arcing time in the contactors is not much more than 0·03 s, i.e. about half a cycle at a frequency of $16\frac{2}{3}$ c/s. This necessitates the provision of a system of magnetic blowout which remains effective at low currents, in conjunction with a high contact speed. Both these requirements are fulfilled by a constructive design which is symmetrical with respect to the horizontal and vertical planes through the axis (Fig. 8). The symmetrical arrangement of the blowout field from two coils ensures that the stresses on the arc chutes are uniform, so that full advantage can be taken of their capacity, while the solution with two moving contacts arranged opposite each other reduces their acceleration by half, and the mechanical stresses to a quarter of what they would be with the normal arrangement with one fixed contact. In addition there is the great advantage of the high-voltage control, i.e. the light currents, as expressed in the light design of the contacts and the small amount of wear by the contact pieces. The reliable shaping of the parts no longer gives rise to any problems in this respect.

During the type tests, the load switches were made to handle currents with r.m.s. values ranging from 235 to 2600 A at 3050 V and a power factor 0·5. The reliability with respect to any imaginable stress likely to occur in service is great.

The operating mechanism as shown in Fig. 8 is a four-cylinder air motor with a crankshaft. By the very nature of its principle this motor can master the dynamic phenomena during switching, either from one tapping to the next or when switching right through the range. It functions without any auxiliary means, such as lock bolts, slip couplings or brakes. The moving masses are accelerated by compressed air and, braked pneumatically, are guided precisely into the desired position.

In the tapping positions the crankshaft is held firm by a pair of pistons under pressure. The sequence in each switching action is that one cylinder is emptied while another is subjected to pressure. By a cyclic succession of these operations between the four cylinders, any number of switching operations can be controlled, depending on whether a single tapping has to be changed or whether a through run is required. The motor functions with a considerable excess of energy, which may be effective in case of necessity, but which is normally absorbed by compression in the cylinders. The "gentle" movement of the motor does much to diminish the mechanical wear on the parts of the tap changer. The valves of the cylinders can be actuated by solenoids or by a remote-controlled cam-shaft.

To gain some idea of the performance of the switching mechanism over long periods, 15 million operations were performed with a 25-kV transformer at full voltage. The results conclusively proved the dependability of this design in the face of severe sustained stresses.

(KME) W. BILLETER

NEW CONTROL SYSTEMS FOR TAP CHANGERS

621.316.543.3:621.335

Two examples are given to illustrate a semi-automatic system of impulse control and a system of voltage divider control employing a transistorized voltage balance. The article concludes with a brief review of possible future developments.

The Problem

THE REMARKS which follow only cover part of the general problem of the control of traction vehicles. They concern the remote control of tap changers and cam-actuated mechanisms driven by servo-motors. This remote control may be from the driver's cab of the vehicle in which the apparatus is mounted, from another vehicle or from a driver-trailer. The stipulated requirements can vary appreciably in nature. For instance, the task to be performed may be to impart a command to the tap changer to run up or down, the movement being continued until it is interrupted deliberately or by means of a limit switch. In such cases it is necessary for the operation in the upwards direction to be supervised by current-limiting relays. But it is often stipulated that it must be possible to select from the controller any one tapping to which the selector runs, either of its own accord, or under the supervision of current relays. With this form of follow-up control the tap changer cancels the command as soon as it runs into the selected position.

The movement of the tap changer can be subjected to the automatic influence of different factors. In addition to the current-limiting relays mentioned above, there may be a relay supervising the braking power, overvoltage or no-volt relays, as well as devices to indicate wheel slip.

Impulse Control System of the RBe 4/4 Motor-Coaches of the Swiss Federal Railways

A detailed description of the high-power motor-coaches, employed on shuttle services between the main centres of the country, is given in a later article (see page 573). The low-voltage tap changer is driven by a four-cylinder air motor. The air pressure is applied to the cylinders and relieved in the right sequence by two pairs of electro-pneumatic valves, which are energized by auxiliary contacts actuated by the crankshaft. For each direction of rotation there is a separate set of contacts, with a contactor for "Up" or "Down", the main contacts of which establish the connection with the source of supply. The operation of the contactors is initiated by a system of impulse control, as illustrated in Fig. 1.

Since the regenerative braking system of these vehicles is also controlled by the tap changer, its operation can also be incorporated in the control programme.

The main drum of the controller 1, shown in Fig. 1, has five motoring positions following the zero in the clockwise direction, and three braking positions in the opposite direction. At the positions marked with a point the tap changer remains on the tapping attained. The negative positions cause it to run down, while the positions "M", "+" and "‡" initiate upward movements, i.e. acceleration The current relays 10 and 11, fed by a current transformer in the traction motor circuit, exert a restrictive action as soon as the current reaches the set limits. On position "+" this is performed by the relay 10, while on position "‡" relay 11, which is set to a higher current value, comes into action. The functional reliability of the two relays is assured by starting windings, which are temporarily energized during the change from one tapping to the next, by the contact *c* of the auxiliary drum 4a of the tap changer. The relay 12, which is set to pick up at a slightly lower value, is used to limit the current during braking.

In order to be able to slow down the rate of switching from one tapping to another, if necessary, the making leads of control contactors 5a and 5b pass via a normally-closed contact of a stepping relay 3 with retarded fall-back. Its operation is controlled by contact *a* of the auxiliary drum in such a manner that the contactors fall back after each step and thus stop the tap changer movement briefly. This time-lag is deliberately effected by placing the controller in the position "M", or it can be automatically controlled via the preliminary current relay 9 when the region of limiting motoring current is approached. By means of the limit contact "I" of the auxiliary drum 4b, the control contactor 5a is disconnected when the tap changer enters the

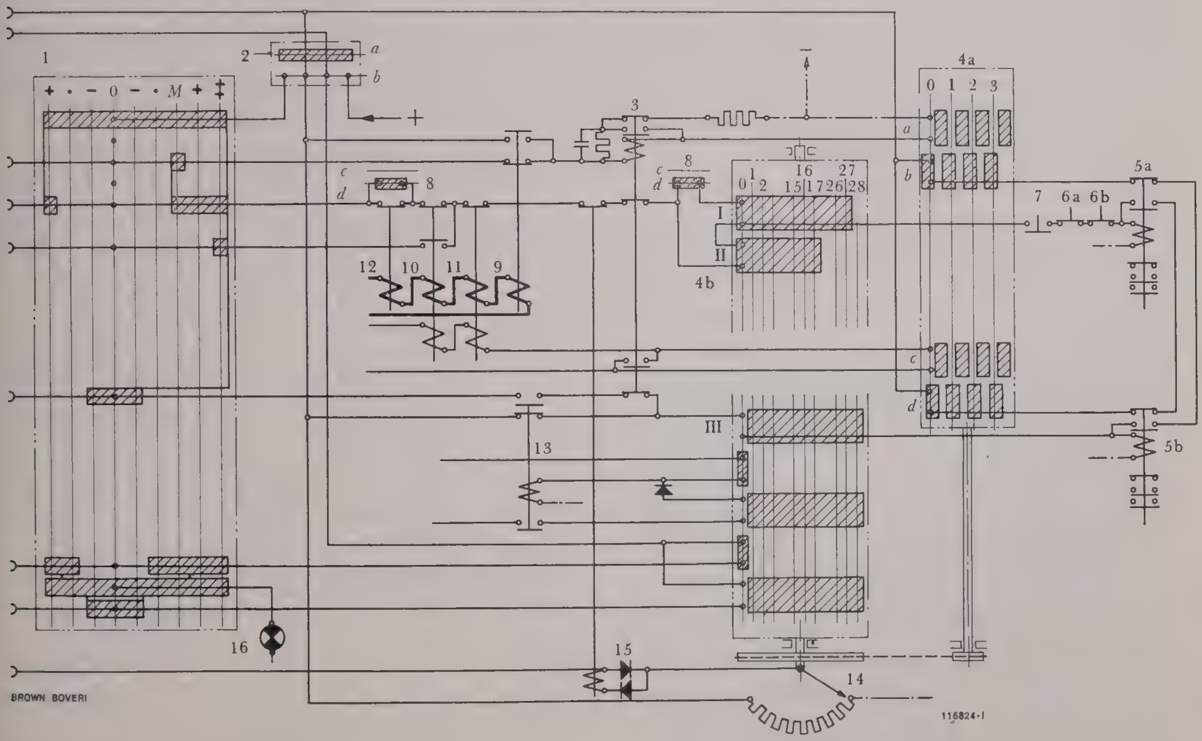

Fig. 1. – Circuitry of a tap-changer control system for motoring and braking (impulse control)

This system is employed in the high-power motor-coaches RBe 4/4 of the Swiss Federal Railways.

1 = Control drum in the controller
2 = Switch for control current *a* = Off *b* = On
3 = Time-lag relay for tap-changer control
4a = Control contact drum of tap changer
4b = Interlocking contact drum of tap changer
5a, 5b = Control contactors for tap changer
6a, 6b = Anti-slip relays
7 = Motor isolating contactor
8 = Control drum of reversing switch
c = Braking *d* = Motoring

9 = Acceleration relay (one-hour current)
10 = Acceleration relay (stage +)
11 = Acceleration relay (stage ++)
12 = Current-limiting relay for regeneration
13 = Interlocking relay for isolating contactor and reversing switch
14 = Potentiometer for synchronizing tap changer
15 = Relay for synchronizing tap changer
16 = Tap changer indicator lamp

top tapping 28. During electric braking this takes place on tapping 18 by means of the adjacent auxiliary contact "II". The drive can also be stopped by opening the motor isolating contactor 7 or when one of the anti-slip relays 6a, 6b, picks up. In the latter case the anti-slip brakes of the vehicle automatically come into action.

The tap changer is usually made to run down by placing the controller in the positions "0" or "–", thereby energizing the control contactor 5b. At high currents it can also take place at reduced speed. If the reversing switch is in the wrong position, or if the reversing drum of the controller switches off prematurely, the control contactor 5b is nevertheless connected with the control voltage direct by the contact of the de-energized interlocking relay 13, so that the tap changer does not cease to run down until the limit contact "III" of the auxiliary switch 4b opens at the bottom tapping.

If several tap changers are jointly remote controlled for multiple traction control, their positions may not agree after a long journey involving frequent switching at very different switching rates. In order to obviate unduly large deviations, a system of "approximate synchronization" was introduced at the suggestion of the Swiss Federal Railways. Each tap changer is equipped with a battery-fed potentiometer 14, the moving contact of which picks off a partial voltage proportional to the position. The moving contacts of all voltage dividers of a particular train are connected via a directional relay 15 to a through line. Due to the unbalance current produced by the difference in position, the directional relays of the leading tap changers are energized and their switching action interrupted until positional agreement is restored. The control contactors 5a, 5b, are kept energized with their armatures attracted—by means of holding lines fed via the contacts *b* and *d* of the auxiliary drum 4a—until the started switching step is completed.

Stepwise indication of the change of position in the driver's cab was dispensed with. Instead, a pilot lamp 16 lights up when the tap changer does not follow the controller into or out of position 0.

This control system, built up almost entirely with the classical elements of light-current control, fulfilled all expectations from the very beginning. It is also held in high esteem by the train crews on account of its easy operation.

Follow-up Control with Transistorized Potential Balance

With follow-up control the controller and the tap changer are equipped with potentiometers fed from a common source of supply, the moving contacts being actuated by the handwheel of the controller, and by the tap changer. The partial voltages tapped off by the moving contact, proportional to the position, are usually conveyed to the moving coil of a polarized relay, the main contacts of which close the command circuit for upward or downward movement of the tap changer, according to the direction of the unbalance current. The command is cancelled as soon as the tapping selected on the controller is reached, thereby de-energizing the polarized relay.

The main advantage of this control system is its simplicity and the small number of control leads required. It does, however, suffer from the drawback that, at low voltage and with a large number of tappings, the voltage difference between adjacent tappings is rather small. The disturbing effect of poor contact increases and quite strict requirements must be imposed regarding the sensitivity of the response of the relays. This is all the more serious, in that the device must be able to cope with the high voltage differences associated with extreme positional deviation, as well as with the rough conditions usually encountered in railway service.

Brown Boveri concentrated their efforts on overcoming these weaknesses, by replacing the sensitive polarized relay by a circuit comprising transistors, resistors and semiconductor diodes. The circuitry of this control system is depicted in Fig. 2. It closely resembles the well-known electro-pneumatic servo system, actuated by energizing a control contactor allocated to the desired direction of rotation. The

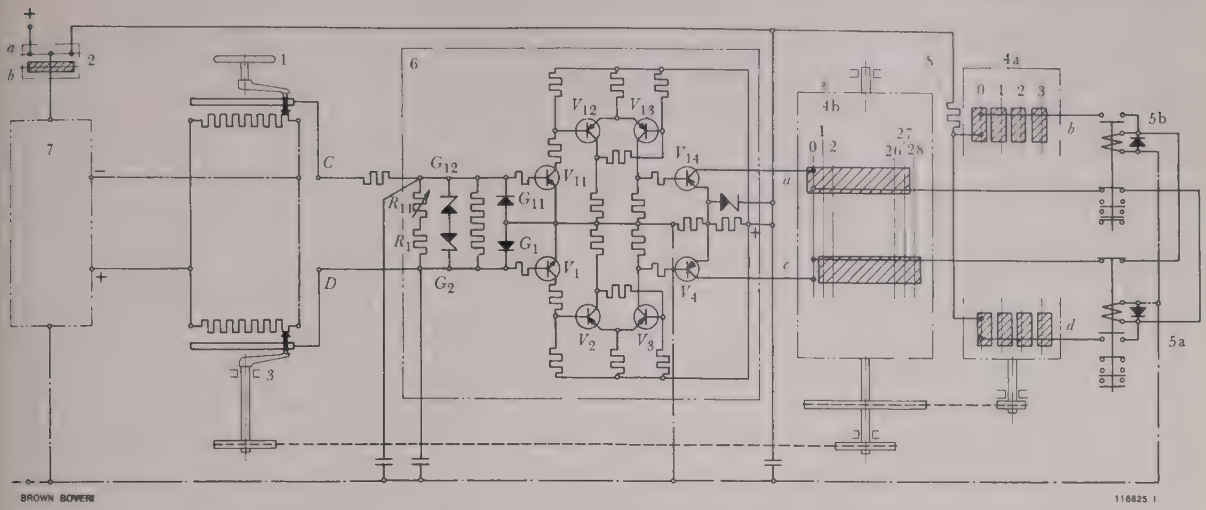

Fig. 2. – Follow-up control with transistorized potential balance

1 = Voltage divider in controller
2 = Switch for control current
a = On   b = Off
3 = Voltage divider in tap changer
4a = Control contact drum of tap changer
4b = Interlocking contact drum of tap changer

5a, 5b = Control contactors for tap changer
6 = Potential balance
7 = D.C. voltage transformer
8 = Series resistor in the holding lead for the control contactors

For other notation see text.

With this system of control the tapping can be freely selected, requiring very few through control leads. By replacing the former polarized relay with a transistor circuit the functional reliability of the control system has been considerably improved.

classical elements of the control system will be obvious at a glance, i.e. the switch 2 for the control current, the voltage dividers 1 in the controller and 3 in the tap changer, the auxiliary drum 4b of which is equipped with the limit contacts *a* and *c*, and finally the contactors 5a and 5b controlling the servo-motor. A second auxiliary drum 4a contains a pair of holding contacts *b* and *d*, through which the contactors 5a, 5b are fed via the holding lines. This ensures that the tap changer performs a complete cycle, in spite of only a brief control impulse being imparted.

The first new element to be described is the d.c. voltage transformer 7 which feeds the potentiometer. In principle, it comprises a vibrator with a complement of transistors, a transformer and a rectifier, and it raises the general control voltage provided by the vehicle battery to a value suitable for the voltage divider circuit. At the same time the inevitable distinction is made between the signal and executive circuits, as required for the transistor circuit.

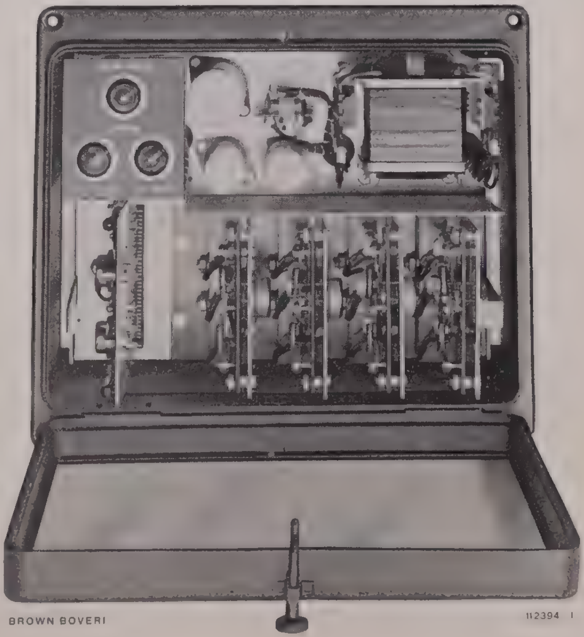

Fig. 3. – Transistorized potential balance with its d.c. voltage transformer feeding the input

The various elements of the circuit are housed in a single casing. Plug contacts allow the unit to be withdrawn and re-inserted very rapidly.

The voltage difference occurring between the pick-offs of the two potentiometers is applied to the input terminals *C* and *D* of the actual potential balance 6. The resistance combination R_1, R_{11} with partially negative temperature coefficients renders the circuit largely insensitive to fluctuation in the temperature. A pair of Zener diodes connected in opposition (G_2, G_{12}) limit the voltage and so protect the succeeding transistors. The directional diodes G_1, G_{11} short-circuit the transistor (V_1 or V_{11}) which is not momentarily conducting. The subsequent bistable circuits (Schmitt triggers) comprising the transistors V_2–V_3 and V_{12}–V_{13} and various resistors lend the system its symmetrical arrangement with respect to the two control contactors 5a, 5b which it has to feed. As soon as the input voltage *CD* exceeds a definite threshold value, lower than the voltage difference of one potentiometer stage, the output state of the transistor collector V_3 or V_{13}—depending on the direction—changes abruptly, causing the associated power transistor V_4 or V_{14} to conduct. The collector current of the latter is sufficient for feeding the contactors 5a and 5b.

The depicted circuit may perhaps appear too extravagant in view of the numerous transistors, resistors and diodes, but this may be contradicted by pointing out that all these elements are small, light and have an almost unlimited life. Fig. 3 shows how the voltage transformer, vibrator and potential balance can be mounted in the protective enclosure of a standard relay casing.

Following exhaustive trials, which have proved extremely successful, this system will be regularly adopted for the first time in the Ae 4/6 locomotive No. 10851 of the Swiss Federal Railways, which is being converted for use on three different supply systems.

Prospects

The example given of follow-up control shows that the restricted but judicious use of electronic elements has succeeded in liberating a classical system from its weaknesses and attaching a new importance to it. An obvious suggestion would be to extend this process to the other elements, a stage at a time, finally modernizing the entire system. The problems of the individual sections are to a certain extent already solved and the elements available. For instance, every push-button of the conventional kind can, with a certain expenditure, be superseded by contactless elements. Nevertheless, overcoming this problem will not necessarily lead to the optimum solution. The control problems must be considered from quite a new angle, on a larger scale, and paying due credit to the special properties and limitations of modern elements. Only by taking this wider view is it possible to arrive at simple, natural and economical solutions. The latter goal is essential if the outcome of this work is to stand out above mere fashionable novelties. The ultimate technical goal is a control system which is not subject to wear, needs no maintenance, is infinitely reliable and lasts for ever. In this respect it may be given new, so far unattempted duties. The progress already made in automation of the tap changing process, for instance, can and will doubtless be considerably extended. At any rate the problems involved are at present being seriously studied. The results will duly be presented in the form of an article in a later issue of this journal.

(KME) A. FEHR

PANTOGRAPH CURRENT COLLECTORS FOR HIGH SPEEDS

621.336.322

The construction of traction vehicles for international routes, on which they are obliged to run off different supply systems, is dependent on very reliable current collection, particularly at high speeds. Moreover the elements employed must comply with the different specifications regarding the nature of the current, the overhead wire, and the profile of the line. The Company's latest development work has culminated in the introduction of an improved type of current collector, the performance of which has been proved in exhaustive trials. This unit is described in the present article.

IN VIEW of the high standard attained by railway engineering it is hardly surprising to find that very strict conditions are laid down regarding current collection. The creation of harmful arcing should be avoided, above all without causing any interruption of the supply, which could be dangerous for the electrical equipment. To approach this goal is the first aim of the designer; but he cannot completely master the problem alone. Far too many factors over which he has no control affect current collection. To begin with, the method of suspension of the overhead wire, its state of repair, and differences in its properties from place to place, or from time to time, can be of decisive importance. Particularly disturbing are points where kinks occur, such as at the points where the wire is suspended. Hoar-frost is a dreaded enemy of the slipper strips, and the effects of snow can be most disconcerting. Even the running properties of the vehicle, and therefore the state of the track influence the flow of current. Finally the shape of the vehicle's nose and the effect of roof superstructures on the flow of air along the roof immediately adjoining it can exert a disturbing effect on the smooth running of the current collector.

Disregarding the rather special sphere of trams and trolleybuses, the pantograph type of current collector has been adopted almost universally. Though light in weight, it possesses excellent longitudinal and lateral stability, while the desired contact pressure, independent of the height of the overhead wire, can easily be obtained.

The actual pantograph frame, though able to follow the slow changes in the height of the overhead wire, cannot cope with the small, abrupt irregularities. For this reason the slipper strips, their carriers and end-shields are combined to form as

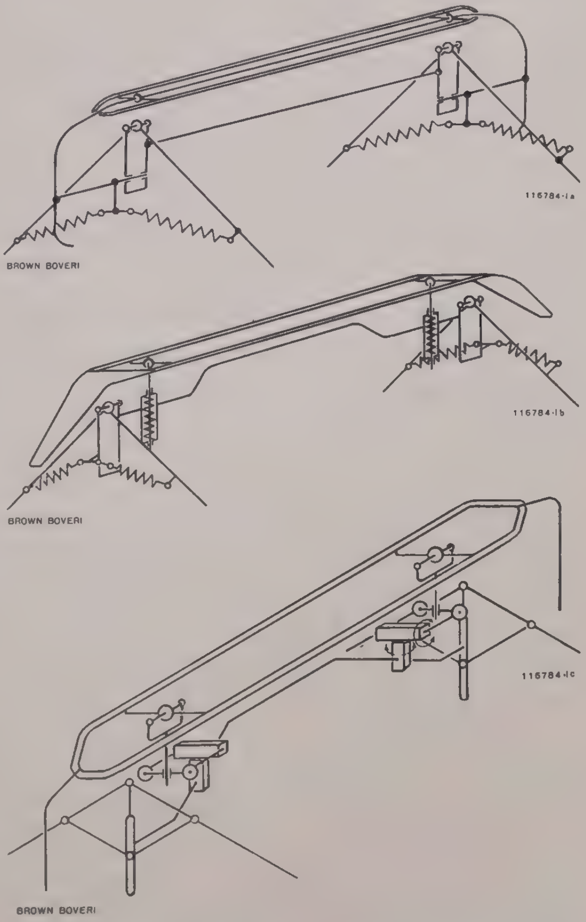

Fig. 1. – Sketches showing three different arrangements for the cradle suspension of current collectors

Top: pendulum-type
Middle: vertically sprung
Bottom: with longitudinal and vertical flexibility

light a component as possible, known as the cradle. This is flexibly attached to the tip of the pantograph in two or three different ways. The many different solutions available in this respect can be traced back to two basic designs: one providing vertical movement, the other with a pendulum movement (Fig. 1). Brown Boveri have developed both systems; the current collectors supplied to the Swiss Federal Railways are equipped with a pendulum cradle devised by the Railways themselves and has proved generally satisfactory up to speeds of 120 km/h, the range in which most Swiss trains operate.

When the Swiss Railways decided to go in for high-speed trains for the Trans-Europe Express service, early in 1958, the question of current collectors became topical once more, in two distinct respects. Firstly, the passage of current had to be assured at speeds of 160 km/h while, secondly, due allowance had to be made for the different supply systems, designs of overhead wires and profile specifications in the various countries.

Current Collectors for International Traffic

The first task was to take an inventory of the main data of the contact wires and current collector of the routes to be covered, in conjunction with the customers. The networks involved belonged to the French National Railways (SNCF), the Belgian State Railways (SNCB), the Federal German Railway (DB), the Netherlands Railways (NS), the Italian State Railways (FS), the Austrian Federal Railways (OeBB) and the Swiss Federal Railways (SBB), the conditions encountered being listed in Table I below.

In view of the considerable deviation in the various data, and above all due to the severe restrictions imposed on the length of the cradle by the profile regulations, the highly favoured idea of an "all-round" collector had to be dropped. It required long discussions carried out under the auspices of ORE (Office de Recherches et d'Essais) between the interested railway authorities before the data of the slipper strips could be modified and mutually arranged so that only four different kinds would be required for through international traffic. In the meantime Brown Boveri had made successful efforts to design a uniform operating mechanism and pantograph unit, to which the different kinds of cradle could be attached, as desired. Allowance had to be made at the same time for the layout of adjacent collectors, the total distance between cradle centres—symmetrical to the bogie pivot—must not exceed 2400 mm. This requirement was fulfilled by making the two collectors interleave

TABLE I

Network		SNCB	DB	SNCF		NS	FS	OeBB	SBB
Kind of supply		D.C.	1-phase 16⅔ c/s	D.C.	1-phase 50 c/s	D.C.	D.C.	1-phase 16⅔ c/s	1-phase 16⅔ c/s
Service voltage	V	3000	15 000	1500	25 000	1500	3000	15 000	15 000
Overhead wire Maximum lateral deviation from centre of track	mm	± 200	± 400[1] ± 650[2]	± 200	± 200	± 350	± 200	± 400	± 200
Height above running surface of rails: minimum	m	4·80	4·95	4·60	4·64	4·85	4·50	4·95	4·95
normal	m	5·10	5·75	5·75	5·75	5·50	5·00	5·75	5·20
maximum	m	6·25	6·20	6·45	6·40	5·70	5·80	6·00	6·50
Slipper strip: Pressure	kg	7·5	7·0	9·0	7·0	12·5[3] 7·5[4]	8·0	6·0	6·0
Material		Carbon	Carbon	Copper Steel	Steel	Metal carbon	Copper Steel	Carbon	Aluminium

[1] Overhead wire in new condition [2] Maximum admissible deviation in service [3] Locomotive [4] Motor-coach

TABLE II

Variant	Network	Kind of supply	Width of cradle mm	Slipper strips	
				Number	Material
I	SBB	1-ph. 16⅔ c/s	1320	2	Aluminium
II	FS, SNCF	D.C., 1-ph. 50 c/s	1450	2	Copper, steel
III	SNCB, NS, (SNCF)*	D.C.	1950	2 × 2	Metal carbon
IVa	DB, OeBB	1-ph. 16⅔ c/s	1950	2	Carbon
IVb	SNCF	D.C.	1950	2 × 2	Copper, steel

* When variant IVa is used

when lowered. An original idea of bending one of the upper arms of the pantograph enabled the two sets of arms to be accommodated in the stipulated space. The areas in which the different types of collectors are employed can be seen in Table II.

Variant IVb will be encountered on the first all-system TEE trains, the employment of which is not at present visualized in Germany and Austria. For use on the Netherlands routes an automatic arresting device is provided to limit the collector height on short sections without any overhead wire, such as over canal bridges.

Improvement of Current Transfer

Exhaustive development work stressed the necessity for improvement of the transfer of current. The basis for this was provided by the results of a number of trial runs carried out some years ago with a Re 4/4 lightweight locomotive of the Swiss Federal Railways. These indicated the advantages to be gained from vertically sprung cradles. Still more conclusive, however, were the extensive experiments performed on the French and Austrian networks with different makes of current collectors by a working group of ORE in 1957. They provide a good picture of the upthrust caused by the air-stream, which of course varies with the speed. The magnitude and direction of this component superposed on the static contact pressure are closely related to the design of the current collector and can be suitably influenced from this aspect.

For the new design a selection was made from several projects and models, the final choice being for a system affording the cradle flexibility not only in the vertical plane, but also in the direction of travel. The suspension system indicated schematically in Fig. 1c is formed in practice by the combination of a pair of levers, attached to rubber torsion elements, to which the cradle is fixed, free to rotate about its main axis, above the upper cross-bar of the pantograph. The number of slipper strips depends on the current carried. For a.c. two are usually sufficient, whereas for d.c. it is necessary to provide three or even four. To ensure that they all exert a uniform pressure on the wire, they are mounted in two separate cradles, one behind the other. Fig. 2 shows a complete collector in the lowered position. On it can be seen the new cradle and the streamlined pantograph, the lifting springs being protected by the easily removable cowling. In contrast to former standard practice, the pneumatic operating system is now earthed. A solid insulator transmits the motion of the piston to the pantograph framework. The weight of the collector, including the 25-kV supporting insulators, is between 240 and 250 kg, depending on the type of cradle.

In order to shorten the development work, as well as giving it some hope of success, repeated use was made of a wind-tunnel, in which fundamental problems were investigated experimentally, or alternative design proposals compared. Fig. 3 shows a prototype ready for testing in the large wind-tunnel of the Federal Aircraft Establishment, Emmen, whose staff were most co-operative in their

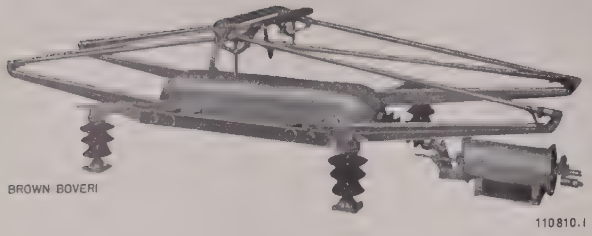

Fig. 2. – Streamlined current collector for high speeds

The extremely lightweight cradle is attached at the top of the pantograph, so that it can move vertically or in line with the vehicle. The elements of the pneumatic mechanism are earthed, the supporting insulators dimensioned for 25 kV.

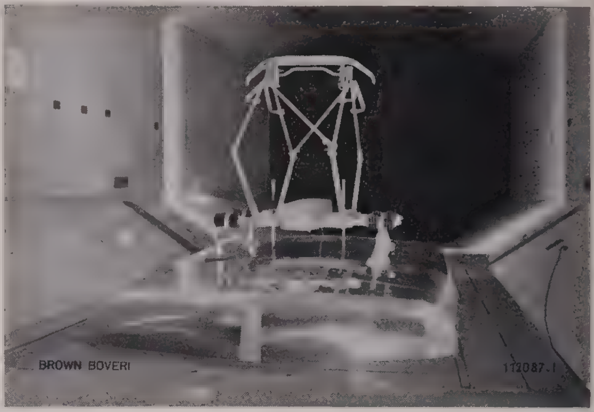

Fig. 3. – Prototype current collector in the wind-tunnel

By testing in the wind-tunnel it was possible to carry out measurements of the upthrust due to the air-stream and to observe the behaviour of the pantograph framework and cradle at speeds up to 180 km/h. In this particular test object the cradle is a variant with only the vertically sprung suspension.

assistance. To stimulate the rising air-stream created by the locomotive, part of the front of its roof was included as mock-up. The upthrust was measured at different heights of the slipper bars, the contact stability of the latter also being determined with the aid of a dummy line. The results confirmed the predominant influence of the cradle assembly, especially of the end-shields, on the contact pressure. With the old designs of collector there was little relationship between the pressure and the speed. With the new model the pressure tends to increase moderately at higher speeds, thus assuring improved current transfer. The upthrust can be influenced to a considerable extent by fitting vanes to the tubes

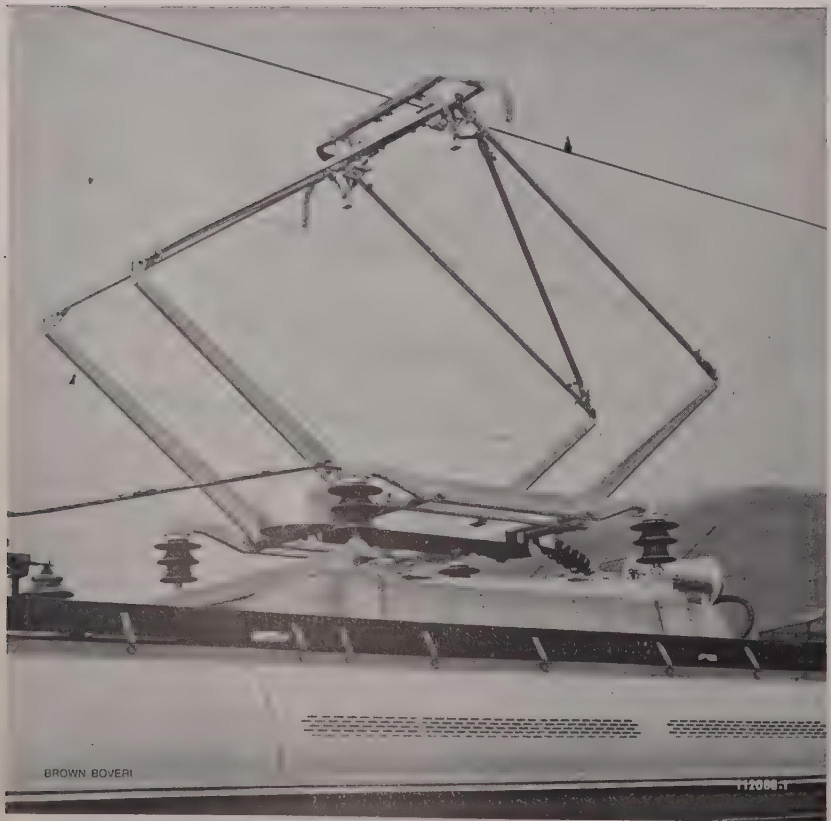

Fig. 4. – Test current collector of the new design on an express train of the Swiss Federal Railways

During the tests, carried out at speeds up to 165 km/h, the upthrust was measured and the behaviour of the cradle observed visually and with the aid of the voltage oscillograms.

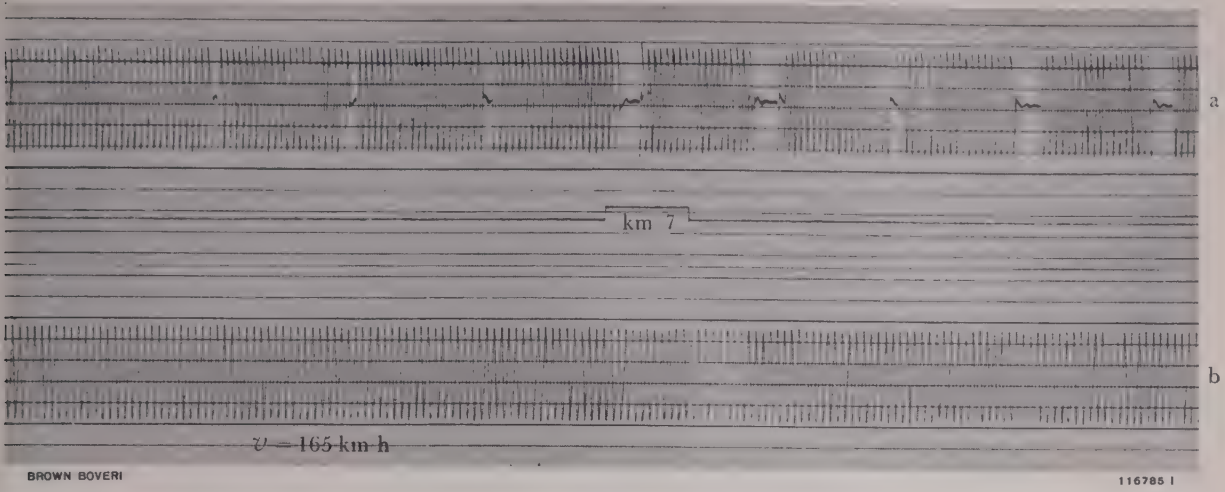

Fig. 5. – Oscillograms showing the voltage when running over an irregular section of line at a speed of 165 km/h

The oscillogram obtained with a pendulum-type cradle of the conventional type (a) indicates numerous interruptions, while (b) recorded with the new Brown Boveri collector is noteworthy for the freedom from interruption.

situated across the air-stream. Less important was the position of the collector on the roof. At air speeds corresponding to 180 km/h the slipper strips of the cradle remained uniform and steady against the contact wire.

Trial Runs

The touchstone for the development work was provided by the exhaustive trial runs. These were carried out by the Rolling Stock and Workshops Department of the Swiss Federal Railways and included a number of collectors and cradles from foreign manufacturers. The vehicle used to carry these test objects was the three-coach composite unit type RABFe 8/12, which was run at speeds of up to 160 km/h or more during the trials. Fig. 4 shows part of the vehicle with the tested collector mounted on its roof. A changeover switch allowed the transformer to be switched at will from the normal collector to the one being tested, so that the behaviour of the latter could be observed with and without current loading. A makeshift periscope constructed of a series of mirrors allowed the cradle to be observed from inside the vehicle when in motion. The sections covered were from Sargans to Walenstadt and from Martigny to Ardon, the second of which is particularly difficult on account of its rather old overhead wiring system, with mast spacings of 100 m. The experimental programme covered the following measurements:

- Upthrust measurements, for which the cradle was held just below the overhead wire by a spring balance attached to a nylon thread.
- Measurements of interruptions at no-load. When the train had been accelerated to 165 km/h, the traction collector was lowered and the voltage at the test object conveyed through a voltage transformer to a cathode-ray oscilloscope and a recording instrument (Minograph), every interruption being indicated by a break in the oscillogram (Fig. 5).
- Measurements of interruptions using the test object as the traction current collector, with the same measuring equipment.

The results of the upthrust measurements agree closely with those obtained in the wind-tunnel. Increasing the speed from 80 to 160 km/h causes the upthrust to increase by about 1 kg.

Fig. 5 shows a section of the voltage oscillogram recorded by the Minograph when the same section was covered with different cradles at the speed of 165 km/h. Whereas the former pendulum type of cradle caused a series of interruptions in the voltage, the trace obtained with the new model is almost completely free from disturbance. Although the formation of sparks can nevertheless still be detected when visually observed, their character and extent are now much less harmful. From comparative observations and measurements it may be claimed that the new Brown Boveri current collector is quite as good as any of its foreign competitors, in some respects superior.

Since the beginning of the year the first collector of this new type has been in regular service on an inter-city express motor-coach unit type RBe 4/4 of the Swiss Federal Railways, which covers over a thousand kilometres every day. Soon it will be helping to supply the power to the Swiss trains of the Trans-Europe Express service, where the conditions will vary considerably.

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VANE-TYPE RESISTORS

621.316.845

A new form of construction for electrical resistance units is described. It is based on the use of strips, similar in shape to turbine blades, spot-welded together in the form of flat grids. Resistors of this form permit appreciably greater power dissipation per unit space and are much lighter and more robust than those of existing designs.

ALL traction vehicles, i.e. locomotives, motor-coaches and trams, are subjected to ever increasing loads, necessitating the accommodation of higher power in the same space. This particularly effects the starting and braking resistors, which, for another reason assume increasing importance. In order to limit wear on the expensive tyres and brake-blocks, greater use is being made of electric braking. There is manifold evidence of a tendency for the braking energy converted into heat in the resistors to be matched to the tractive power. The conventional resistor design employing corrugated resistance strip does not meet these demands. New, more efficient designs had to be evolved. By developing the resistors described below Brown Boveri have made an interesting contribution to the solution of the problems involved.

Design Principle of the New Resistors

Fig. 1 shows how the curved, vane-shaped resistance elements, mounted on edge and in banks, are assembled to form a compact grid. Several grids, according to requirements, can be arranged one above the other with their convex faces in alternate directions, thus causing the stream of cooling air to continually change direction as it passes through the vane assembly. The natural direction of the air-flow is upwards from below, but the reverse direction can be effected by the use of forced-draught cooling.

It is clear from Fig. 1 that this type of construction permits excellent utilization of the available space, without impairing the cooling air stream through the vanes.

The curved vane elements, even when thin resistance strip is used, are rigid and self-supporting, thereby eliminating the need for a special supporting framework. The present design is the outcome of various considerations based on exhaustive test results. The form of the curve of the vane is a compromise between the desired sectional stiffness and the permissible resistance to air flow. The intermediate space between the individual vanes is primarily governed by the quantity of air needed to dissipate the heat. Its rate of flow within the vane-grid is limited by the pressure drops and by the possible stimulation of vibration. The minimum vertical distance between edges of the vanes of any two adjacent grids is dependent on the voltage difference experienced. The number of the resistance grids to be assembled above one another is governed by the quantity of heat to be dissipated by each unit, the maximum pressure drop associated with the rate of flow, the highest permissible temperature of the resistance materials and the maximum air exit temperature, which in turn is limited by the resistance to heat of the casing materials. The quantity of air and pressure drop determine the size and rating of the blower supplying the cooling air, the outlay for which should be taken into consideration when determining the optimum dimensions of the resistance unit.

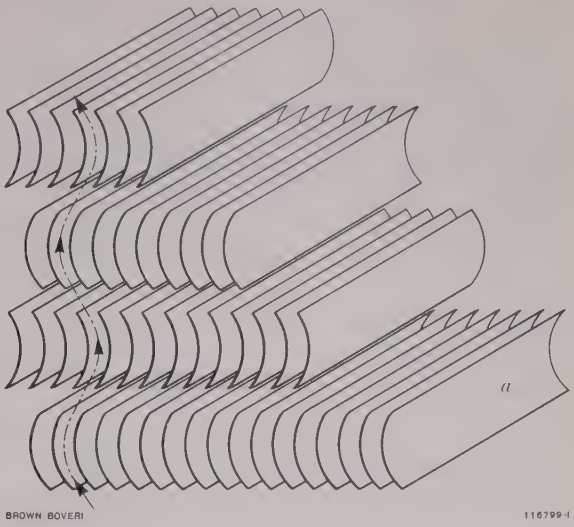

Fig. 1. – Principle of construction of a resistor comprising vane-shaped elements

a = Vane-type element

Drawout Design of the Vane-Type Grid

The aims on which development work was based were:

Increased power for the same space as before,

High power-weight ratio,

Thermal strength at elevated temperatures,

Resistance to thermal shock of all ceramic insulation,

Resistance to vibration even under unfavourable operating conditions, e.g. in diesel powered vehicles,

Freedom from corrosion of all metal parts.

These aims have been realized with the vane-type resistor shown in Fig. 2. The most important component of the new resistor is the vane itself *a*, manufactured from high-quality rust-proof resistance strip. Electrically it represents a resistance element. Its hollow form lends it a remarkable rigidity even when very thin strip is used.

The support *b* is the connecting and supporting element for the vanes, to which it is spot welded. It is so formed, as a bending and shaping element, that the thin vane material is surrounded by thicker rust-proof material at the welding points. The tools for manufacturing supports are designed for mass production.

The contact stud *c* is the electrical connection between resistance grid and cable connection in the case of naturally-cooled resistors. On resistors with forced-draught ventilation and enclosed in a housing, the stud *c* acts as a plug-pin which, together with a corresponding socket contact fitted inside the casing, makes the external connection. It consists of a silver-plated copper stud welded into the vane support at suitable points by a special method.

In its form as a resistance grid the welded assembly is a combination of a large numbers of vanes and supports. Welding such a grid demands special

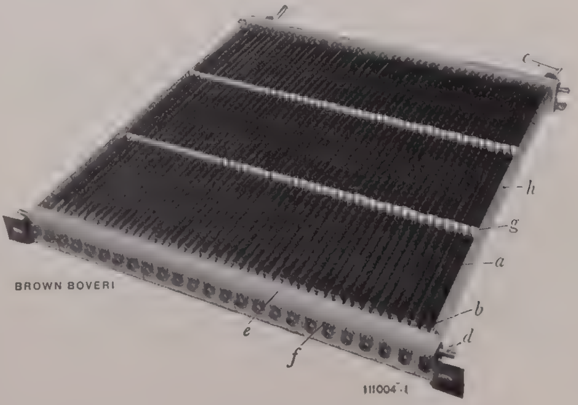

Fig. 2. – Vane-type grid in drawout form

a = Vane
b = Vane support
c = Contact stud
d = Pressure stud
e = Ceramic rider
f = Spring ring
g = Space
h = End vane

fixtures to ensure rapid, consistent and reliable work. Before being passed over to inspection each grid is brought to red-heat to check the welds. The two outer vanes *h* of thicker material are not electrically stressed. They serve as mechanical protection and, in the case of forced-air-cooled resistors, prevent unduly intensive heat radiation to the wall of the casing.

The Insulating Crossbars

The welded resistance grid is of course a very flexible assembly; hence it has to be held by and yet insulated from its surroundings. Using ceramic riders placed over two studs *d* and thus pressed together, two rigid bars are formed, the cylindrical stubs of the vane supports being inserted in the set of holes in the two bars. Spring rings *f* secure the connections and stiffen the whole assembly (Fig. 2). In the case of forced ventilation, the ends of the pressure studs projecting beyond the ends of the insulating crossbars form a slide device mating with slide rails fitted on the sides of the casing, whereas naturally ventilated resistors have special insulators, acting as a second insulation against the roof mountings.

Intermediate Spacers

Two rows of ceramic spacers *g* serve as additional security for the intermediate spaces. They are pushed in between the vanes, their lugs resting in the slots of the vanes so that they cannot turn or fall out. These two sets of spacers improve the rigidity of the grid. Furthermore they reduce the risk of contact between any two vanes in the event of an overload or short circuit. From Fig. 2 it can be seen that only these ceramic pieces are in direct contact with the hot vane elements.

Socket Contacts

The drawout system of forced-air-cooled resistors assumes that reliable contact is made when the resistance grid is inserted. The parts involved in this must be of such a nature that they create negligible mechanical resistance when the assembly is pulled out. In addition they must suit the small unit spacing and be flexible in all directions to allow for play. The contact chosen consists of only four parts: a contact stud, two contact shells and a leaf spring pressing the two shells together.

Resistor Blocks

For ratings above about 2000 kW the roof arrangement of naturally cooled resistors is almost impossible, even though space requirements may create no problem. In such cases resistors cooled by an intense forced draught have to be provided, sufficient space being available in most cases; the vane-type resistors require but a fraction of the space taken up by strip-type resistors of the former design. A resistor block consists of four to twenty drawout units assembled one above the other, closely surrounded by a chimney of heat-resistant insulating plates, in the upper or lower portion of which a propeller-type cooling fan is installed.

Separately mounted centrifugal fans can also be employed.

As mentioned previously, the resistance grids can be pushed into the block casings in the manner of a drawer (Fig. 3). When the number of drawers is complete, each of their insulation bars form a ceramic wall at the front and rear, screening off the actual high-temperature space. Following the rear ceramic wall is a small intermediate space, also ventilated, and then the true chimney wall. On the inside this carries the socket contacts and on the outside the connections and terminals. The front wall of the chimney consists merely of a cover to prevent the drawers from working loose due to vibration. The cover can be arranged with catches to facilitate dismantling.

Simplicity and suitability mark the design of the resistor block. For opening up and replacing a drawer only a few manipulations are necessary. The smooth finish of the vane surface exposes it to a minimum of contamination, in addition to which

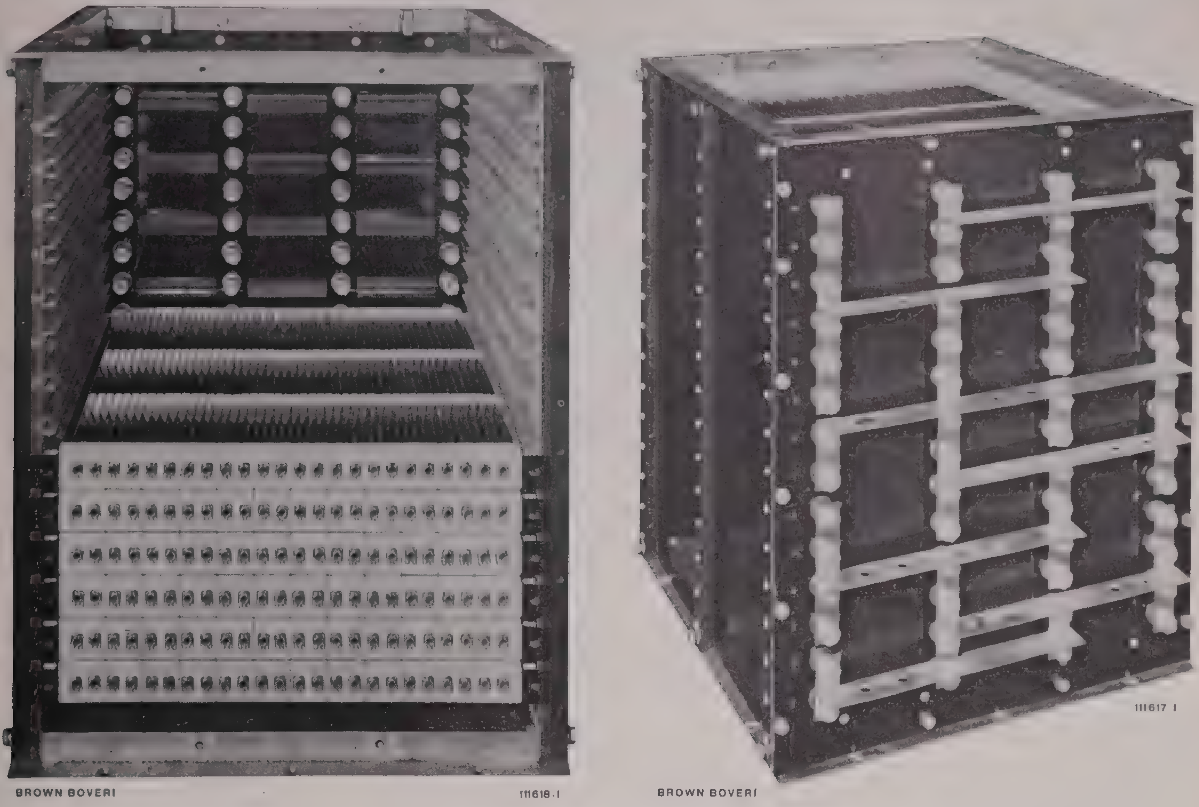

Fig. 3. – One of the starting resistor blocks of the three-system locomotive Ae 4/6 III, of the Swiss Federal Railways

a: Front wall of chimney removed showing some of the resistor drawers, the guide-rails and the socket contacts.

b: Rear view showing the terminals and the connections between the resistor drawers.

drawers can be thoroughly blown out on removal. The effective space occupied by a powerfully ventilated resistor can, under favourable conditions, be reduced to 0·18 m^3 for 1000 kW. The following figures show the relative weight and volume of vane-type resistors, compared with the former strip type:

Former strip resistors	Vane-type resistors
Weight % 100	50 — 60
Volume % 100	20 — 40

Naturally-cooled vane-type roof resistors are completely weatherproof; only non-rusting metal parts and ceramic materials resistant to thermal shock being employed.

Fig. 4 shows part of the braking resistor mounted on the roof of the new high-power motor-coach of the Schweizerische Südostbahn (see page 574). Owing to their extremely low construction they fit inconspicuously into the contour of the vehicle. In

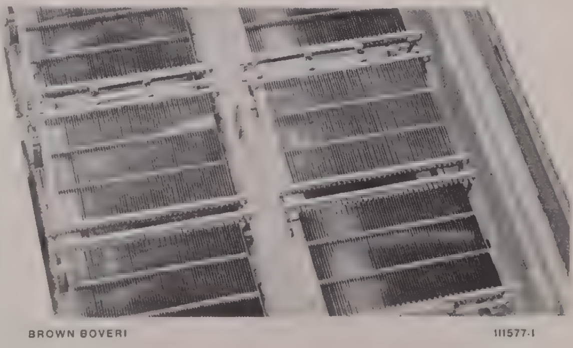

Fig. 4. – View showing the arrangement of resistors on the roof of a motor-coach

The wire mesh protecting the resistors from foreign bodies has been removed. Owing is their large, intensively cooled surface area, the resistors can dissipate a large amount of power in a very small space.

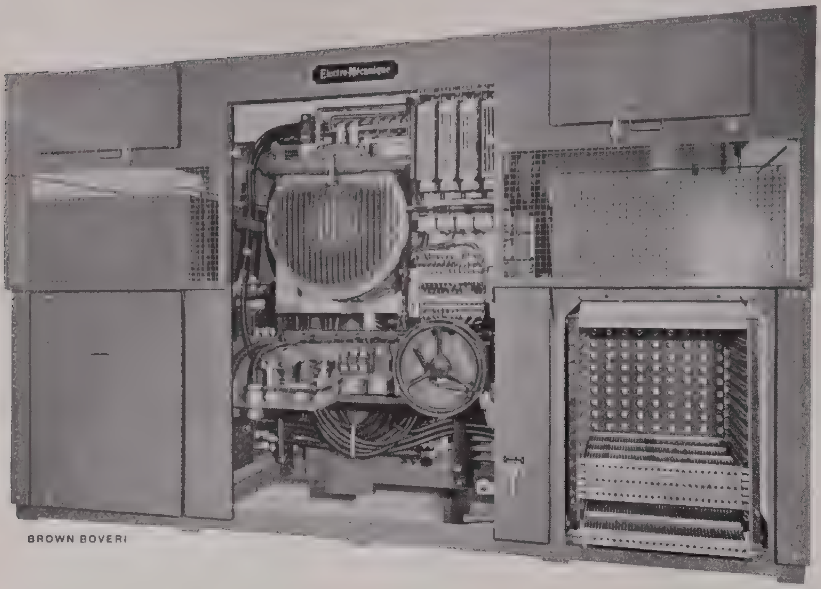

Fig. 5. – Apparatus block of a d.c. locomotive series 9400 of the French National Railways (SNCF)

Next to and behind the central control gear are a total of six resistor blocks.

addition, they permit the braking power to be increased to 1300–2000 kW for short periods. This would have been almost impossible with resistors of the conventional design.

Fig. 5 shows an apparatus block of the latest d.c. locomotives of the French National Railways (SNCF). Two of the six existing resistor blocks are visible. The front cover and some of the drawout units are removed from the right-hand side block, showing the remaining drawers, their guide-rails and the socket contacts. Each block is provided with a cooling fan, mounted above. In this case the cooling air for the resistor is drawn out of the machine room and forced downwards. At present a total of 116 such locomotives are being built, the first of which are already in regular service.

The development of the vane-type resistor is a valuable contribution to the problem of increasing power and saving weight in modern traction vehicle construction.

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NEW LOCOMOTIVES AND MOTOR-COACHES FOR SINGLE-PHASE SUPPLIES AT $16^2/_3$ c/s

621.335.025.1

The traction vehicles for single-phase supplies at 16⅔ c/s, as described in the present article, demonstrate clearly that, with this current system, which, in its time, gave the impetus for electrification of main-line traction in Switzerland, Germany, Austria, Sweden and Norway, it is possible to fulfil all requirements of modern railway traffic under all circumstances.

LOOKING BACK on the history of the evolution of electric traction, we discover that there has always been a great deal of lively discussion between the specialists regarding the most suitable supply system for the electrification of railways. This question is by nature extremely complex and concerns not only the actual sphere of electric traction, but also that of generation of the power and distributing it to the substations. To the purely technical and economical problems which form the basis of such discussions, but which are dependent upon regional conditions, both as regards the character of the railway network and the manner in which the power is generated and distributed, which in turn are governed by the present state of engineering as such, there must be added commercial and political aspects, which render an objective comparison between the different supply systems extremely difficult. However, it may justly be claimed that the three main systems employed for main-line traction, i.e. d.c. at 1500 or 3000 V, single-phase a.c. at 15 kV, 16⅔ c/s, and finally single-phase a.c. at 20–25 kV, 50 c/s, are capable of fulfilling all operational requirements, including the most exacting.

Whereas for completely new electrification projects, where there is no need to allow for existing networks carrying electric traffic the 50-c/s system is the one likely to be selected, the other two systems nevertheless have retained their full justification, when it comes to the renewal and extension of existing railway networks. This applies most particularly to the system with 15 kV, 16⅔ c/s, which in its time was decisive for the realization of main-line electric traction in Switzerland, Germany, Austria, Sweden and Norway. The principal Alpine routes in Europe, providing facilities for north-south traffic, as well as east-west—Lötschberg, Simplon, Gotthard, Arlberg, Brenner, Tauern and Semmering—all operate off this supply system.

The new locomotives and motor-coaches to be described below impressively demonstrate that the progress made in the design of traction vehicles in recent years has opened up numerous possibilities which not so long ago were considered unthinkable; on the other hand electric traction with single-phase a.c. at 16⅔ c/s has proved to be capable of fulfilling all modern operational requirements.

The Ae 8/8 Locomotive of the Berne-Lötschberg-Simplon Railway (BLS)

This locomotive, the main dimensions, performance and the principal feature of the electrical equipment of which are given in the Table on pages 578/9, is in effect a modification of two well-known $B_0'B_0'$ locomotives type Ae 4/4 [1][1] rigidly coupled together, and owes its inception to the development of transport conditions on the BLS route in the last few years [2].

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[1] The figures in square brackets refer to the bibliography at the end of the article.

The goods wagons of European railway undertakings engaged on international traffic having been equipped with reinforced draw and buffing gear, it became possible to increase the admissible trailing load in 1956 to 900 t for the gradient of 2·7% which occurs on long stretches of the Lötschberg line. This fact facilitated the concentration of goods trains on that line, allowing heavier trains to be hauled without intermediate or pusher locomotives having to be employed for the upgrades. Much as this concentration may appear desirable, having regard to the increased traffic on this route, which is only single-line for much of its length, it could not be achieved with the then available traction units, namely the $(1'C_0)$ (C_01') locomotives of the Ae 6/8 series and the $B_0'B_0'$ units of the Ae 4/4 series, as these vehicles, though excellent in themselves, were only able to haul loads of 600 and 430 t, respectively. As soon as a goods train weighed 600–900 t, which applies to about 25% of all trains on this route, it was necessary to run with duplicate locomotives, involving the return journey of the extra locomotive and its crew.

The haulage of a 900 t train at a top speed of about 75 km/h up the gradient of 2·7%—i.e. a speed comparable with passenger trains—demands a locomotive with eight powered axles, each with a pressure of 20 t, in other words, double the capacity of the Ae 4/4. This involuntarily gives rise to the idea that it should be just as easy to cope with the traction programme with a pair of Ae 4/4 locomotives coupled for multiple control, as with a large, inseparable double unit. Detailed investigations by BLS in the meantime have, however, proved that the Ae 8/8 double locomotive, whose bogies, traction motors and almost all electric and pneumatic

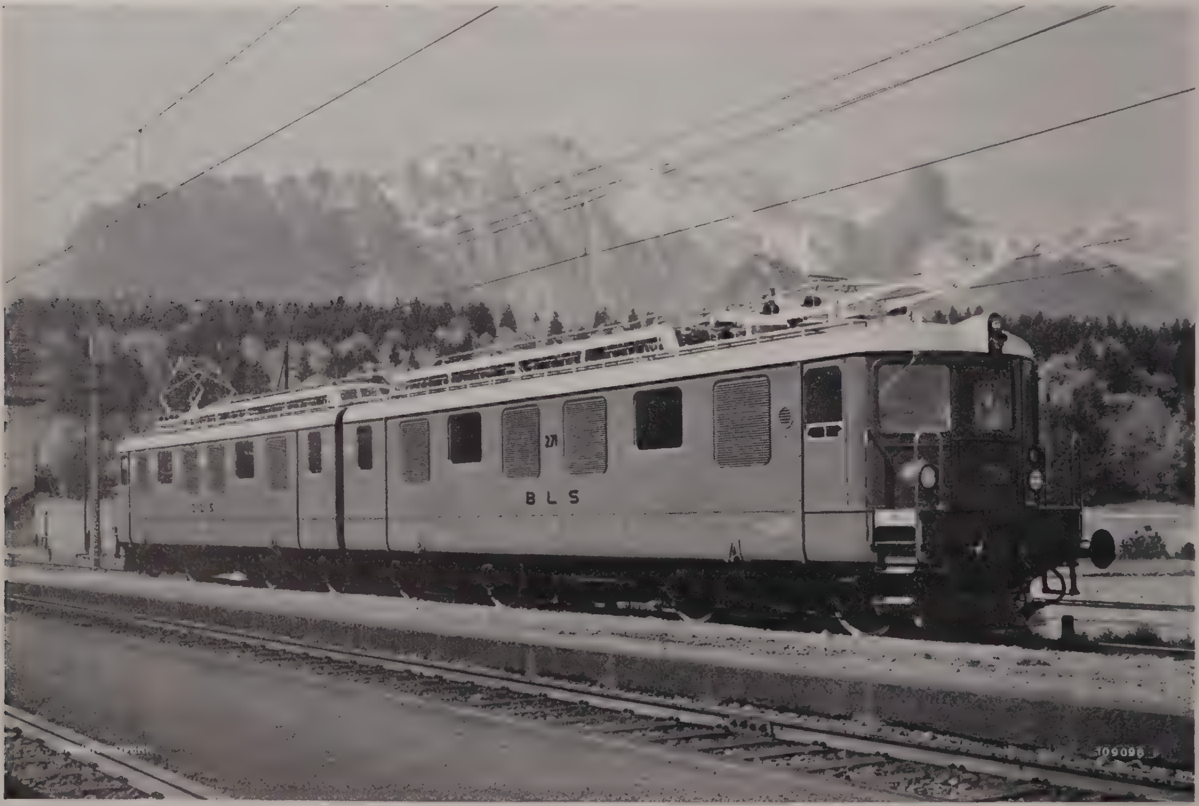

Fig. 1. – The Ae 8/8 locomotive No. 271 of the Berne–Lötschberg–Simplon Railway (BLS)

The power developed by this vehicle enables it to haul goods trains weighing up to 900 t up the 2·7% gradients of this line at the speed of passenger trains, thus accelerating and improving traffic on this very busy route.

equipment, with the exception of the transformer, are interchangeable with the corresponding elements of the Ae 4/4 locomotives already in service, is a more economical solution, because, in comparison with a pair of Ae 4/4 with multiple control, two complete driver's cabs with all their equipment can be dispensed with, and a number of other simplifications are also possible.

The Ae 8/8 locomotive taken into service in 1959 (Fig. 1) is equally capable of hauling heavy passenger or goods trains, but on account of its power is primarily reserved for the transit goods traffic, where it has fulfilled all expectations and contributed to a general speeding up in traffic on the BLS route. Indeed, so successful has it been that a second unit was ordered in the summer of 1960.

The mechanical part of the vehicle was built by the Swiss Locomotive and Machine Works (SLM), Winterthur. The design of the superstructure closely resembles that of two Ae 4/4 units, although the two adjoining ends—in the middle—are somewhat different, due to the elimination of the two driver's cabs and the provision of an articulated coupling and a communication bellows between the two halves.

Whereas the body of the Ae 4/4 locomotive is supported on the bogies by leaf springs, the Ae 8/8 is fitted with rubber suspension; in conjunction with the axle-box springs, which are designed for increased resilience, they improve the already excellent running properties.

The torque of the traction motors is transmitted to the axles through the classic Brown Boveri disc drive, which has already proved most efficient on the Ae 4/4 locomotives.

The electrical equipment corresponds essentially to that of the Ae 4/4 locomotives, the first six of which (No. 251–6) were converted by the BLS to correspond to the last two (No. 257/8) and equipped with reinforced rheostatic braking. The main features of the electrical equipment are as follows:

- Airblast circuit-breaker as main switch.
- Radially laminated transformer for h.v. control [3] with an increased traction power of 3080 kVA continuous, compared with 2700 kVA of the Ae 4/4.
- High-voltage tap-changer control with linear selector contact track, two load switch elements and electric motor operation. The simultaneously actuated tap-changer drives of the two halves are mechanically coupled by articulated shafts, thus assuring synchronism of the two tap changers.
- Traction motors of the same design as used for the Ae 4/4, i.e. separately ventilated, 14-pole compensated series commutator motors with a 10% higher one-hour rating, this increase being obtained exclusively by correspondingly increasing the torque, i.e. tractive effort.
- Rheostatic braking, the traction motors of each half being excited with d.c. supplied by a generator driven by one of the motors driving the traction-motor fans. With this electrical braking system the locomotive with a train weighing 500 t can be braked to a steady speed on a downgrade of 2·4–2·7%, without the pneumatic brakes having to be employed. When the Oerlikon pneumatic brake is simultaneously applied on position "R", the locomotive can be powerfully braked at a uniform rate from any speed.
- Warm-air heating in the driver's cab; in the summer, the fans which draw the fresh air in through one side and force it through heaters into the cab, can be utilized for ventilation alone. Owing to the slight excess pressure thereby created in the cab, it is possible to eliminate the draught which is usually almost unavoidable.

The Motor-Coaches type RBe 4/4 of the Swiss Federal Railways (SBB)

The new rolling-stock programme laid down in 1956 by the SBB included the procurement of quite a large number of powerful motor-coaches of the type RBe 4/4, having a one-hour rating of about

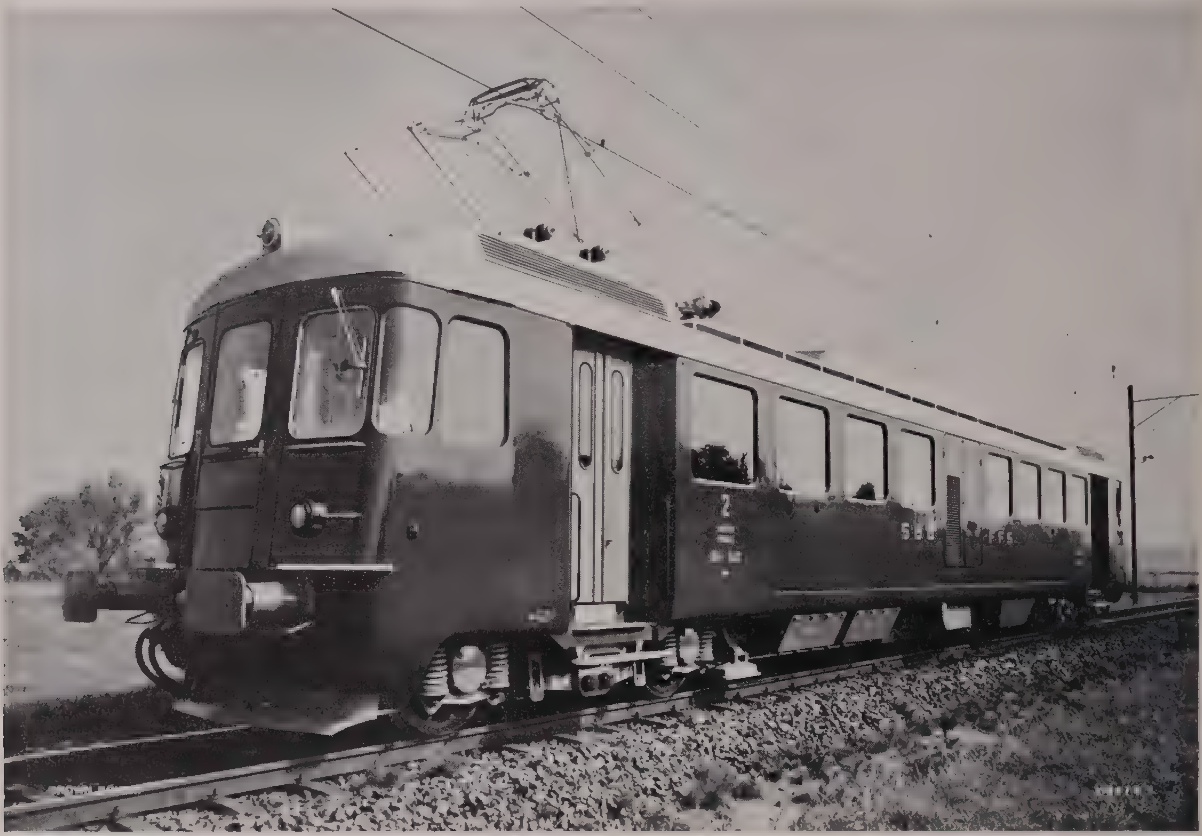

Fig. 2. – Motor-coach type RBe 4/4 of the Swiss Federal Railways (SBB)

This versatile vehicle can perform traction duties which were formerly reserved for locomotives.

2500 hp and a top speed of 125 km/h. They are thus just as powerful as the Re 4/4 locomotives [4] or the $1'C_01'$, $2'C_01'$ and $2'C1'$ locomotives of the Ae 3/5, Ae 3/6 III and Ae 3/6 II series, dating back to 1920, and can undertake the same traction duties in a better and, above all, more economical manner. With modern design techniques it is possible to construct such traction vehicles as motor-coaches instead of as locomotives, thus allowing shuttle-services to be run and appreciably reducing the haulage costs. Technical and operational considerations have proved the motor-coach to be an ideal solution; its seating capacity allows one four-axle coach to be saved, thereby reducing the weight and the length of a train.

In 1959 the six motor coaches type RBe 4/4 ordered by the Rolling Stock and Workshops Dept. of the SBB and built by the Swiss Industry Co. (SIG), Neuhausen, MFO, Oerlikon, and Brown Boveri, acting in close collaboration, were taken into regular service (Fig. 2); they were immediately subjected to an extremely severe practical test, in that they were employed to haul express inter-city trains covering a total distance of 1200–1500 km every day, with trailing loads of more than 300 t. These motor-coaches, whose one-hour rating was finally fixed at 2060 kW (2800 hp) are extremely versatile. They can be used not only for express trains, but also for fast passenger or goods traffic on main and branch lines, upon which a speed of 80 km/h may be attained on gradients of 2·6% with a trailing load of 210 t. When starting up from standstill with the same load and gradient, this speed is attained in about 60 s. This excellent acceleration can be utilized to shorten the travelling time, which is most valuable for local traffic. Conforming to the operational requirement for forming shuttle-service trains where possible, the motor-coaches are equipped for multiple and remote control.

The contract for the supply of the electrical equipment was divided up in such a way that this Company was entrusted with the airblast circuit-breakers, the radially laminated transformers with a continuous rating of 1760 kVA + 500 kVA for heating and 60 kVA for auxiliary services, also the low-voltage tap changers with their air motors and control gear, the master controllers, etc., as well as the erection of the electrical equipment in three of the six vehicles; other Swiss firms were given the job of providing all traction motors, reversing switches and regenerative braking equipment and erection of the other three vehicles. Also on our order was the supply of the spring drives for all six vehicles, and all current collectors.

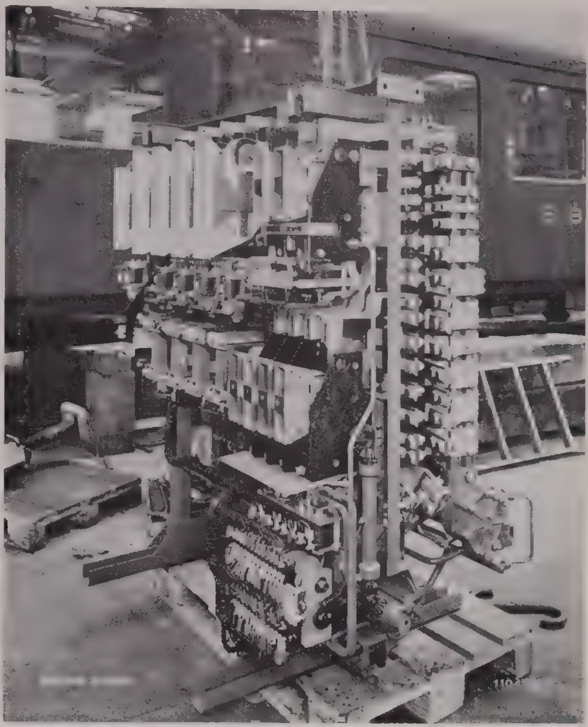

Fig. 3. – Control gear sub-unit of the motor-coach shown in Fig. 2

At the bottom in the foreground is the air motor with control block for the l.v. tap changer; above it are the four load switches and the two transfer contactors. Left of these are four electro-pneumatic motor isolating contactors and the heating contactor, also electro-pneumatic. On the extreme right can be seen the two reversing switches, one for each pair of traction motors.

For the installation of the electrical equipment every effort was made to occupy as little of the interior of the body as possible. In the interest of easy maintenance it is assembled in easily dismantled sub-units. The transformer with its forced air cooling and the built-on selector of the l.v. tap changer, is beneath the floor of the coach, together with the regenerative braking gear. The switchgear compartment in the middle of the coach, accessible from the corridor and from outside, contains the load switches, the pneumatic operating gear and control relays of the l.v. tap changer, the reversing switches which also establish the braking connections for both directions of travel, together with the four electro-pneumatic isolating contactors for the motors (the contactors were supplied by Ateliers de Sécheron, Geneva). This control gear is combined to form a compact block as shown in Fig. 3. The motor-driven fans for cooling the traction motors are mounted in the roof above the entrance platforms; they draw in the cool air through louvres above the doors and force it down vertical ducts on one side of each door, followed by a horizontal section and a flexible tube, to the motors. On the roof is the current collector with the airblast circuit-breaker, the earthing link, the h.v. input cable carrying the current to the transformer, and the resistors which act as ohmic shunts for the interpoles.

The neatly arranged driver's cab (Fig. 4) contains all controls, likewise arranged on the block system. The impulse system of control for the l.v. tap changer allows the master controller to be accommodated in a very compact space—a great advantage in view of the limited space available; its handle-operated main and directional drums being mechanically interlocked in the usual manner.

The Motor-Coach type ABe 4/4 of the Schweizerische Südostbahn (SOB)

One of the salient features of the service of the SOB is that its route has long stretches with up-grades of as much as 5% and, at times, has to cope

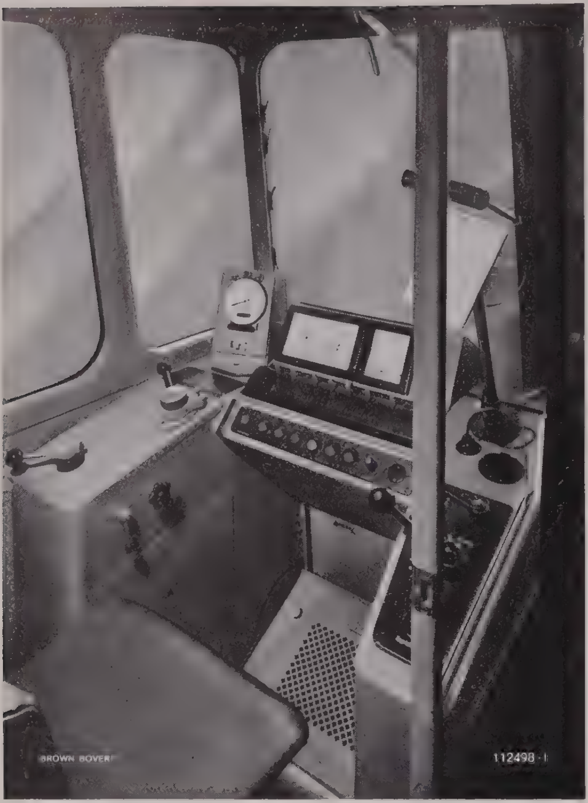

Fig. 4. – View in the driver's cab of the RBe 4/4 motor-coach

The right-hand section of the desk, with master controller, instruments, control switches and pilot lamps is constructed on the block system. This whole section can be withdrawn from the cab through the end door. Left, in the fixed section, from front to back: speedometer, driver's brake valve of the automatic pneumatic brakes and the shunting brake, as well as the windscreen-wiper switch and rear-view mirror.

Fig. 5. – Motor-coach type ABe 4/4 of the Schweizerische Südostbahn (SOB)

used for hauling heavy passenger trains up gradients of 5%. On flat stretches this unit can attain a speed of 110 km/h and is thus also suitable for excursion traffic over all standard-gauge sections of Switzerland's railway network.

with extremely severe peak-load traffic—it is the direct link between eastern and central Switzerland and has to carry tourist traffic in summer, winter sports' enthusiasts in the winter, as well as pilgrims to the world-famous shrine at Einsiedeln. The increased traffic provided the incentive for the SOB to procure a new traction vehicle, the capacity of which had to considerably exceed that of the former motor-coaches. Exhaustive investigations proved that, particularly under the severe operating conditions, the high-capacity motor-coach (Fig. 5 and 6) is by far the most expedient and most economical unit. In conformity with the operational requirement that the motor-coach must be capable of hauling a trailing load of 125–155 t up a gradient of 5%, the one-hour rating of the four traction motors was made 1620 kW (2200 hp), developing a tractive effort of 10 500 kg at the wheel rim at a speed of 55 km/h. On pronounced flat stretches it may develop a top speed of 110 km/h.

Fig. 6. – View inside the passenger compartment of the ABe 4/4 motor-coach of the SOB

The elegant, comfortable furnishings of this compartment, together with the smooth running qualities of the vehicle, ensure that all travellers enjoy a pleasant journey.

The steep inclines of the SOB route necessitate the provision of efficient electrical brakes. The type ABe 4/4 motor-coach possess a separately excited d.c. resistance braking system with separate armature circuits, permitting the train to run at 60 km/h with a trailing load of 100 t down a 5% incline, without using the pneumatic brakes. Furthermore, when running into stations it can be employed as an effective retarding brake over a wide range of speeds. The braking resistors mounted on the roof are of the vane-shaped type described in the article beginning on page 566 of this issue, and are naturally cooled by the current of air created by the movement of the vehicle. A novel feature is the excitation of the fields of the traction motors, connected in series for braking, by a static excitation unit comprising a supply transformer, a set of transductors and a set of selenium rectifiers, all mounted in an oil-filled tank. The braking effort is controlled in fine stages by varying the premagnetization of the transductors with a variable resistor in the master controller.

For controlling the traction motors the low-voltage tap changer is also employed in this case, driven by an air motor; its assembly corresponds exactly to that in the SBB motor-coaches type RBe 4/4 described earlier in this article. The control system of the tap changer, on the other hand, is a follow-up system, with which, if necessary, switching up to the desired motoring tap can be automatically supervised by relays monitoring the acceleration of the vehicle by limiting the increase in current. The motor-coach is designed for multiple and remote control and is thus suitable for use on shuttle services.

The motors driving the fans of the traction motors, and mounted in pairs in the roof above the driver's cabs, also those driving the fans for the oil coolers beneath the floor, are normal d.c. series motors fed from the single-phase auxiliary supply through dry-type rectifiers. This method of supplying the auxiliary motors, which has given excellent results on single-phase traction vehicles for 50 c/s, is beginning to assert itself for 16⅔ c/s supplies. The extra

Table giving the main dimensions, rating data and features of the traction

Undertaking	BLS	SBB
Type of vehicle and duties	Locomotive for hauling heavy passenger and goods trains over the Alps with gradients up to 2·7 %	Passenger motor-coach with 68 2nd class seats. Used for hauling all kinds of trains, but mainly inter-city express shuttle service
Series designation and service numbers	Ae 8/8, 271	RBe 4/4, 1401–6
Gauge	1·435 m	1·435 m
Axle arrangement (as per UIC)	$B_0'B_0' + B_0'B_0'$	$B_0'B_0'$
Length over buffers	30·23 m	23·7 m
Overall distance between axles	26·13 m (11·5 m per half)	19·6 m
Axle spacing of bogies	3·25 m	3·0 m
Diameter of driving wheels (new)	1·25 m	1·04 m
Adhesion = tare weight	160 t (80 + 80 t)	64 t empty, 70 t full
One-hour output at motor shaft	6472 kW (8800 hp)	2060 kW (2800 hp)
Corresponding tractive effort at wheel rim, at a speed of	30 600 kg 76 km/h	9160 kg 80·4 km/h
Maximum starting tractive effort at wheel rim	appr. 46 000 kg	17 000 kg
Top speed	125 km/h	125 km/h
Drive and gear ratio	Brown Boveri disc drive 1:2·22	Brown Boveri spring drive 1:2·74
Data of traction motors (one-hour rating)	809 kW at 395 V, 2300 A and 720 rev/min	515 kW at 420 V, 1380 A and 1160 rev/min (MFO)
Electric braking system	Rheostatic with d.c. excitation from separately excited generator	Regenerative with exciter-motor circuit (MFO)
Main breaker	Airblast circuit-breaker type DBTF 20 i 200	Airblast circuit-breaker type DBTF 20 i 200
Main transformer	Brown Boveri radially laminated, with h.v. control	Brown Boveri radially laminated, with l.v. control
Traction motor control	H.V. tap changer type N 28 h driven by electric motor; follow-up control, 28 steps for motoring	L.V. tap changer type NU 28 with air motor, semi-automatic impulse control, 28 motoring steps, multiple and remote control

vehicles described, for single-phase supplies at 15 kV, $16^2/_3$ c/s

SOB	SOB	BT
Motor-coach with 17 1st-class seats, 32 2nd class and 4 tip-up seats. Heavy passenger trains for gradients of 5%	Passenger and baggage motor-coach with 32 2nd-class and 4 tip-up seats. Direct passenger traffic up gradients of 5%	Passenger and baggage motor-coach with 32 2nd-class and 4 tip-up seats. Direct passenger traffic up gradients of 5%
ABe 4/4, 71	BFe 4/4, 81	BFe 4/4, 50
1·435 m	1·435 m	1·435 m
$B_0'B_0'$	$B_0'B_0'$	$B_0'B_0'$
23·7 m	23·7 m	23·7 m
19·5 m	19·5 m	19·5 m
3·0 m	3·0 m	3·0 m
1·04 m	1·04 m	1·04 m
69 t empty, 74 t full	70 t empty, 76 t full	70 t empty, 76 t full
1620 kW (2200 hp)	2100 kW (2860 hp)	2100 kW (2860 hp)
10 500 kg 55 km/h	10 500 kg 72 km/h	10 500 kg 72 km/h
19 000 kg	19 000 kg	19 000 kg
110 km/h	110 km/h	110 km/h
Brown Boveri spring drive 1:2·78	Brown Boveri spring drive 1:2·78	Brown Boveri spring drive 1:2·78
405 kW at 295 V, 1600 A and 805 rev/min	525 kW at 380 V, 1600 A and 1050 rev/min	525 kW at 380 V, 1600 A and 1050 rev/min
Separately excited, transductor controlled d.c. rheostatic brakes with separate armature circuits	Separately excited, transductor controlled d.c. rheostatic brakes with separate armature circuits	Separately excited, transductor controlled d.c. rheostatic brakes with separate armature circuits
Airblast circuit-breaker type DBTF 20 i 200	Airblast circuit-breaker type DBTF 20 i 200	Airblast circuit-breaker type DBTF 20 i 200
Brown Boveri radially laminated, with l.v. control	Brown Boveri radially laminated, with l.v. control	Brown Boveri radially laminated, with l.v. control
L.V. tap changer type NU 28 with air motor, semi-automatic follow-up control, 28 motoring steps, multiple and remote control	L.V. tap changer type NU 28 with air motor, semi-automatic follow-up control, 28 motoring steps, multiple and remote control	L.V. tap changer type NU 28 with air motor, semi-automatic follow-up control, 28 motoring steps, multiple and remote control

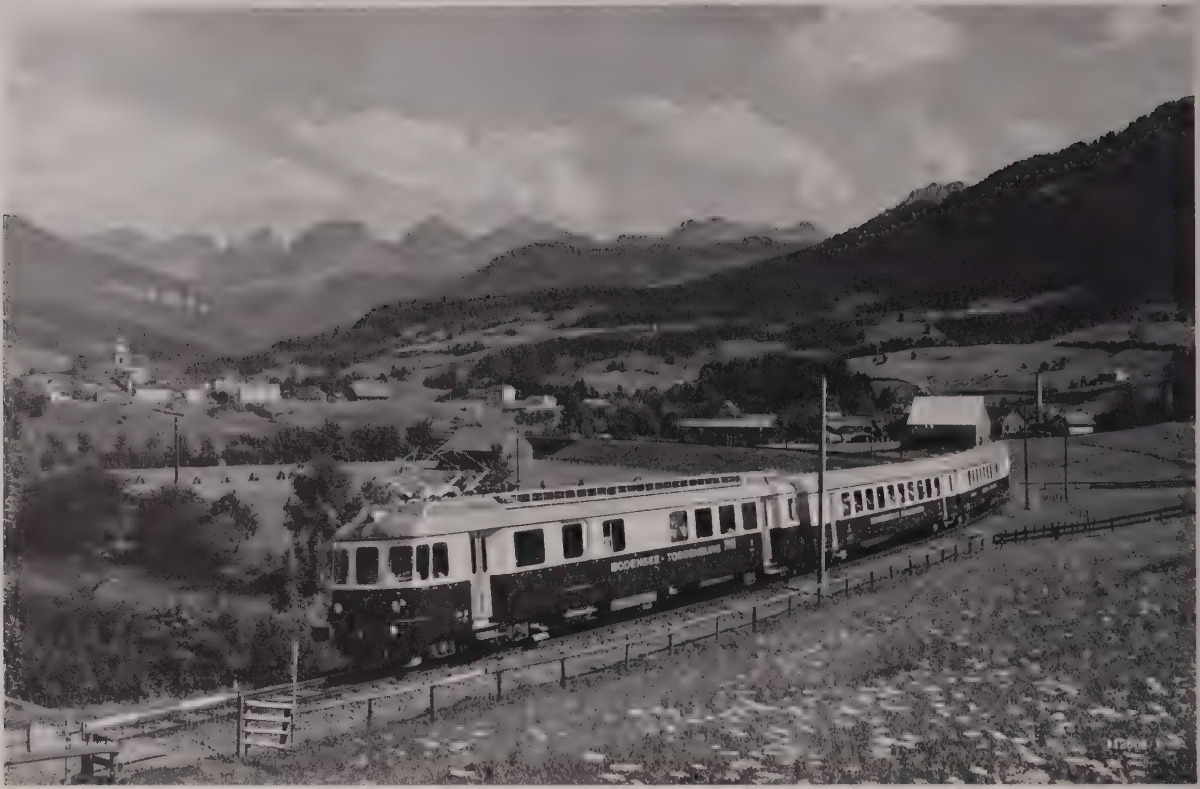

Fig. 7. – Motor-coach type BFe 4/4 of the Bodensee–Toggenburg Railway (BT) with a shuttle-service train composition

This train, like that of the SOB in Fig. 8, is engaged on direct traffic between central and eastern Switzerland.

outlay for the dry-type rectifiers is more than compensated for by the ability to use lighter, cheaper and less sensitive d.c. motors for the auxiliaries.

A further interesting detail is the statically controlled battery charging unit (with supply transformer, magnetic amplifier, dry-type rectifier and transductor regulator). A small smoothing choke reduces the pulsation of the current for the interior lighting, so that it is impossible to detect any flicker in the filament lamps when operating at $33^1/_3$ c/s, i.e. twice the supply frequency.

The BFe 4/4 Motor-Coaches of the SOB and the Bodensee-Toggenburg Railway (BT)

The direct passenger traffic between central and eastern Switzerland is handled not only by the SOB, but also by the SBB (Rapperswil–Wattwil line) and the BT (Wattwil–Herisau–St. Gall–Romanshorn), all three undertakings contributing to the provision of the traction vehicles to haul through trains, and the passenger coaches and luggage wagons. Since, on the one hand, the increased traffic necessitated the employment of more traction vehicles by the SOB and BT and, on the other, because both undertakings intended to purchase new rolling stock in any case, to modernize and increase the capacity of their routes, they were finally able to order two almost identical motor-coaches of the type BFe 4/4.

Both motor-coaches (Fig. 7 and 8) are equipped for multiple or remote control, which is primarily utilized for shuttle services. It is, of course, quite permissible to incorporate both these vehicles in the same train composition and control them from the motor-coach or driver-trailer which happens to be at the head of the train. The same form of duplicate traction can be effected by combining one of these vehicles with the ABe 4/4 motor-coach of the SOB although it is not possible to double the trailing load on account of the difference between the tractive effort/speed characteristics.

The only difference in the electrical equipment of these two motor-coaches from that of the preceding unit is that their transformers are rated 1715 kVA continuous, instead of merely 1550 kVA. This allows exactly the same type of traction motors to be operated at a higher terminal voltage, thereby developing a one-hour output of 2100 kW (2860 hp); with unchanged tractive effort at the wheel rim of 10 500 kg it is therefore possible to step up the speed to 72 km/h, compared with 55 km/h. Thus the two BFe 4/4 motor-coaches are able to separately haul a load of 450 t up a slope of 1% at a speed of 77 km/h, while maintaining the one-hour current of the traction motors; they can also haul 300 t up a slope of 2% at 72 km/h or 250 t up 2·5% at the same speed, and finally 125 t up 5% at 65 km/h.

Except for the transformers, all elements of the electrical equipment of these two vehicles are identical with those of the ABe 4/4, and interchangeable, thus greatly simplifying the spare parts' problems of these two undertakings.

(KME) E. Isler

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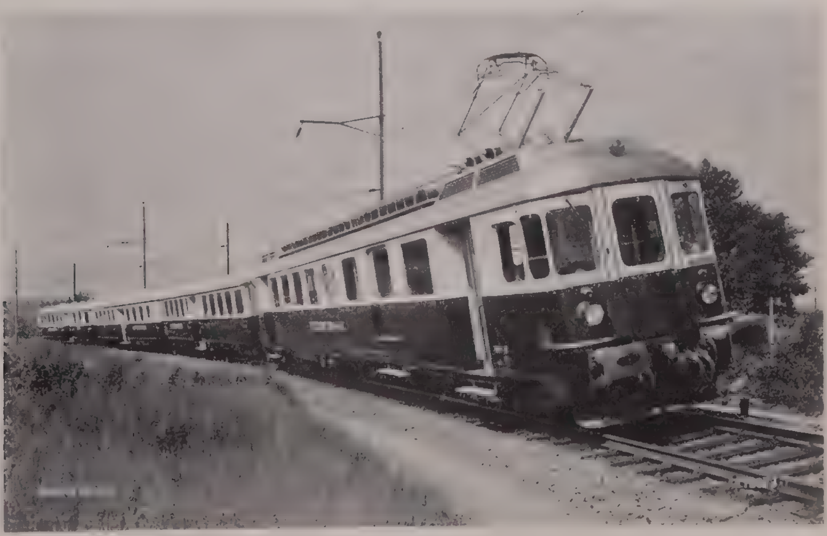

Fig. 8. – Motor-coach type BFe 4/4 with a shuttle-service train of the SOB

50-c/s AND MULTI-SYSTEM TRACTION

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The article is introduced with a review of the development of 50-c/s traction. The reasons for the success of traction vehicles using the industrial frequency of 50 c/s are examined, and a modern rectifier locomotive is briefly described. The author next reports on the spread of the 50-c/s system throughout the world, considering particularly Portugal and India. The problems of multi-system traction are illustrated by some examples taken from actual practice and, in conclusion, the question of future development is raised.

The Importance of Electric Railway Operation with the Industrial Frequency of 50 c/s

TRACTION at 50 c/s has arisen from the efforts to render the operation of electric railways as economical as possible. Whereas, before the second world war, conversion to electric operation took place mainly on lines with particularly heavy traffic, or difficult traction conditions; in the process of restoring the partly destroyed West European railway networks after 1945, a search was made for ways of extending the advantages of electric traction to less intensively loaded sections, whose electrification would not have been justified with the system formerly employed, i.e. direct current at 1500 V or 3000 V, or single-phase alternating current at low frequency. It is significant that the 50-c/s system was introduced for the first time on a large scale by the French National Railways (SNCF), in an attempt to obtain a system which would prove economical even for those lines with less intensive traffic, in addition to the well-developed network at 1500 V d.c. The development of the 50-c/s system in France began immediately after the conclusion of the electrification of the Paris–Dijon section at 1500 V d.c. which involved heavy capital expenditure. The original objective, namely to obtain a cheap traction system for branch lines, was not only achieved, but surpassed by a wide margin.

The present article will concentrate solely on the problem of traction vehicles for 50 c/s. The remaining aspects of the system, such as the direct supply from the general grid, via simple transformer substations, and the light overhead wire resulting from the high voltage employed, are mentioned here merely for the sake of completeness. Although the asymmetric load imposed on the three-phase network by single-phase operation was initially considered a serious problem, it soon became apparent that this no longer represents a barrier to the extension of the 50-c/s system, in view of the size of present supply networks. As a rule of thumb, the relation $\frac{P}{P_K}$, i.e. the relation of the single-phase load to the short-circuit capacity, at the point at which the power is taken, should not exceed 5%. This relation also corresponds approximately to the asymmetry factor of the voltage.

Review of the Development of 50-c/s Traction

In looking back upon the development of the single-phase traction system with the industrial frequency of 50 c/s, which is now being extended with extraordinary rapidity, three stages can be distinguished:

1. Up to about 1950, in the attempt to save on the fixed installations, it was accepted that the traction vehicles for 50 c/s exhibited considerable disadvantages, when compared, on the one hand, with the well-known high-performance vehicles for 1500

or 3000 V d.c. supplies, or with those for single-phase a.c. at a voltage of 15 kV and a frequency of 16⅔ c/s. At that time both these systems had reached a high stage of development. The locomotives for 50 c/s, however, were either of relatively low power (traction vehicles with single-phase commutator motors), or involved complicated equipment (locomotives with rectifiers, sometimes water-cooled design with vacuum pumps, or with large converter sets). Electrification schemes carried out up to 1950 were mainly of an experimental character, and were restricted to three regions, namely:

Budapest–Hegyeshalom [1][1]	Length of the line	192 km
	Inauguration	1932
Höllental Railway (Black Forest) [2]	Length of the line	36 km
	Inauguration	1936
Annecy–Aix-les-Bains–La Roche (SNCF) [3]	Length of the line	78 km
	Inauguration	1949/50

These first schemes demonstrated that the 50-c/s system is technically practicable, provided the above disadvantages for the traction vehicles can be accepted.

2. The second phase is marked by the first application of the new system to a longer line with very heavy traffic, namely the section in Northern France between Valenciennes and Thionville [4]. This line connects the Lorraine area producing iron and steel with the heavily industrialized northern part of the country and the region around the Channel ports. All credit is due to the SNCF for their courage in applying the system, which at that time was still in its infancy, to the whole of this vital transport artery at one sweep, particularly when it is considered that, of the four different locomotive types ordered, only one, i.e. that with directly fed traction motors, could be regarded to any degree as proven in practice. The following four types were placed on order:

15 $B_0'B_0'$ locomotives with single-phase commutator motors

5 $B_0'B_0'$ locomotives with ignitron rectifiers and pulsating-current motors

20 $C_0'C_0'$ locomotives with single-phase/three-phase converter sets of variable frequency and squirrel-cage motors

60 $C_0'C_0'$ locomotives with a.c./d.c. converter sets and d.c. motors.

The electrification of the Valenciennes–Thionville line was a complete success. In particular, it was found that the performance of the various types of locomotives exceeded all expectations, and surpassed the requirements of the specification in respect of permissible train tonnage by a generous margin. This was especially the case with the locomotives of the 12 000 series, equipped with ignitron rectifiers and pulsating-current traction motors. The first locomotives of this series, hauling trains of 1400 t or more, were able to start in a 500-m curve with a gradient of 1%, although only 750 t was prescribed. Locomotives of this series built subsequently have a different gear ratio and can regularly handle 1650 t on a gradient of 1%.

The results attained with the above four types of locomotive acted as a kind of natural selection, from which the ignitron locomotives emerged as the most successful type. This fundamental experience revolutionized the whole development of the 50-c/s traction vehicle, so that, since then, the rectifier locomotive commands the field. The reasons for this clear advantage of the rectifier locomotive will now be examined more closely.

As a result of experience gained on the Valenciennes–Thionville line, 50-c/s traction had within a short time become a completely developed system, in which each individual component was technically at least the equal of the corresponding components of the classical systems. The inexpensive fixed installations were naturally an economic advantage in favour of the new system. The most interesting fact emerging from the experience on the Valenciennes–Thionville line was, however, that a series of new possibilities was revealed, extensive use of which was made in the years that followed.

3. The third phase is not yet concluded, and is marked by two facts. Firstly, a number of new locomotive types have appeared which, in various

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[1] The figures in brackets refer to the bibliography on p. 597.

Network	SNCF	SNCF	SNCF	Russian Railways	Indian Railways
Series	16 000	16 500	20 104	GF	20 200
Type	$B_0'B_0'$	$B'B'$	$B'B'$	$C_0'C_0'$	$B_0'B_0'$
Commissioned	1958	1958	1958	1959	1959
Voltage	25 kV, 50 c/s	25 kV, 50 c/s	25 kV, 50 c/s	25 kV, 50 c/s	25 kV, 50 c/s
Maximum continuous rating . . . hp	4920	3500	4880	5500	2840
Maximum continuous tractive effort . . . t	15·2	11·5/19·2	20·1	32	14·5
Corresponding to speed . . . km/h	85	82/48·5	64	47	52
Maximum speed . . . km/h	160	140/85	105	100	112
Weight of the electrical equipment . . . t	38·9	28	40·4	52·6	32·5
Total weight . . . t	84·4	68	84·7	138	74·5

respects, have a very high performance. Summarized data of some examples of these are given in the table above.

All the locomotives mentioned in the table are equipped with water-cooled ignitron rectifiers, except the SNCF locomotive No. BB–20104 and some of the series 16 500, which have rectifiers of the excitron type. On all these locomotives the voltage is controlled by high-voltage tap changers of Brown Boveri manufacture.

The main circuit diagrams of most of these locomotives closely resemble one another; this is a further indication of the high state of development which the rectifier locomotive has now reached. Differences are still apparent in the arrangement of the auxiliaries. In some cases, alternating current is generated by an Arno converter, which feeds the squirrel-cage motors of the auxiliaries; in other cases d.c. motors, fed by a small dry-type rectifier set, are used for these drives.

The second characteristic of the contemporary development of 50-c/s traction is its rapid spread throughout the world. Not only has it become the preferred system for new electrification schemes, on account of its economic advantages, but it has made the electrification of railway lines so attractive that many countries which would otherwise have turned to diesel traction or continued with the steam as used hitherto, are engaged in converting their most important railway lines to electrical operation.

Reasons for the Success of 50-c/s Traction Vehicles, Especially Rectifier Locomotives

If it becomes possible to make better use of the rolling friction of a traction vehicle than was previously the case, i.e. by increasing the adhesion coefficient, a step forward has been made in the entire traction field, because the same train weight can be hauled at lower cost. Before commissioning the first rectifier locomotives, it was anticipated that the employment of the adhesion, as offered by this type, would be feasible. The practical results nevertheless exceeded all expectations. The rectifier locomotive proved to be a major advance in traction techniques. It fulfils the following conditions, conducive to the attainment of a high coefficient of friction:

a. *Parallel connection of the traction motors*

The traction motors of rectifier locomotives may be permanently connected in parallel, as is the case with the new $16\frac{2}{3}$-c/s vehicles. In this event, wheel-slip on one axle has no effect on the other axles. But with d.c. locomotives, in order to reach a certain economic number of steps, or a favourable voltage for the traction motors, it is necessary to connect two or more traction motors in series for starting. If one set of wheels commences to slip, the traction motor concerned removes the voltage from the other series motors driving the axles which are not slipping. The torque of these other motors is thereby reduced. An exception is the 9400 series of d.c. locomotives of SNCF, which start up with traction motors connected in parallel.

b. *Constant terminal voltage*

When starting up d.c. locomotives, a resistance which causes a certain voltage drop must be placed in series with the traction motors. If the wheels slip, the current drawn and the voltage drop in the resistance are reduced, as a result of the higher speed; the voltage at the motor terminals, however, increases, because the voltage of the overhead wire across both resistance and motor remains practically constant. The speed of the slipping motor is further increased as a result of the higher terminal voltage, and the slipping is aggravated. But with a.c. locomotives, in which the voltage applied to the traction motors is not regulated by resistances but by transformer tappings, the terminal voltage is predetermined at every step and practically constant, except for the voltage drop in the transformer. The terminal voltage, therefore, does not substantially increase if slipping sets in.

c. *Slope of the tractive effort-speed curve*

If the torque of a traction motor decreases severely when the wheels it drives slip, i.e. when a certain increase of speed occurs, the slip may be expected to cease of its own accord. If, on the other hand, there is only a small decrease in torque with increasing speed, the axle will continue to slip. In other words, a high value of the quotient $\frac{\Delta Z}{\Delta V}$, i.e. a steep slope of the curve of tractive effort in function of the speed, reduces the tendency to slip. Now for pulsating-current motors fed by rectifiers the tractive effort-speed curve is very steep so that their behaviour is very favourable in respect of slip, in contrast to single-phase commutator motors, especially for 50 c/s, whose speed-torque curve is less steep (Fig. 1).

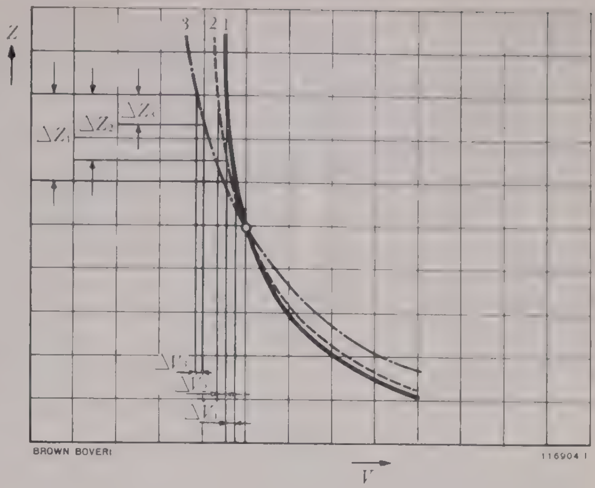

Fig. 1. – Simplified curves of tractive effort against speed

Z = Tractive effort V = Speed

1 = Pulsating-current motor
2 = Single-phase commutator motor for 16⅔ c/s
3 = Single-phase commutator motor for 50 c/s

It is assumed that $\Delta V_1 = \Delta V_2 = \Delta V_3$
and that $\Delta Z_1 > \Delta Z_2 > \Delta Z_3$

It is justifiable to assert that rectifier locomotives offer a unique combination of the advantages of d.c. vehicles with those of the classic low-frequency, single-phase a.c. traction vehicles.

This combination of the individual advantages of existing systems is found not only in the basic theoretical considerations, but also in the construction of individual components. Equipment already highly developed for the 16⅔-c/s system, such as main circuit-breakers, tap changers and transformers, can today be employed without a great deal of modification for the 50-c/s system. It is particularly gratifying to note that important equipment of Brown Boveri design is found in nearly all 50-c/s traction vehicles built up to the present. This applies particularly to the airblast circuit-breakers employed for both locomotives and motor-coaches, and to the high-voltage tap changers, which have found almost universal acceptance for the relatively large outputs which have to be handled.

It cannot be denied that the rectifier locomotive is more complicated than the classic d.c. locomotives or a.c. locomotives with single-phase commutator motors. The rectifier was a new element in the traction field and foreign to railway practice, therefore extensive and costly development work, accompanied by a certain number of failures, was necessary before the rectifier in its various forms could be adapted to railway operation, and able to operate reliably and without undue maintenance or excessively complicated auxiliaries, despite rapid fluctuation of the ambient temperature and load. Today various types of rectifier are being successfully employed:

- Ignitrons, i.e. single-anode mercury-arc rectifiers, in which the arc is re-ignited every half wave;
- Excitrons, i.e. single-anode mercury-arc rectifiers in which there is a permanent excitation arc;
- More recently, semiconductor rectifiers, especially silicon diodes.

The majority of the locomotives at present operating are equipped with water-cooled ignitrons.

Rectifier locomotives gives rise to current harmonics on the primary side of the transformer, i.e., in the supply network, the voltage drops of which produce voltage harmonics. The more the pulsating current produced by the rectifier is smoothed, the greater the harmonic content of the primary current. In practice the ripple is kept down to between 20 and 30%, for the sake of the traction motors on the one hand and owing to the cost of smoothing chokes on the other. With regard to the harmful effect of current and voltage harmonics in the primary system caused by rectifier locomotives, it can be maintained that these remain within permissible limits, as long as the condition for the limitation of the asymmetric loading of three-phase networks is observed, i.e. $P/P_K < 5\%$, as referred to above.

Example of a Modern 50-c/s Locomotive

In the course of the electrification of the Basle–Réding line, the SNCF ordered in Switzerland four two-frequency locomotives, for operation at 25 kV, 50 c/s and at 15 kV, 16⅔ c/s. Two of these locomotives, namely BB–20103 and BB–20104 (formerly BB–30003/4) are distinguished by a number of innovations, both in the electrical and mechanical equipment. The electrical equipment of these two locomotives was ordered from Brown Boveri, while the Swiss Locomotive and Machinery Works in Winterthur manufactured the mechanical part under the guidance of the SNCF. The following remarks apply to locomotive No. BB–20104, designed as a goods locomotive for a maximum speed of 105 km/h (Fig. 2).

The single-motor bogies are the most interesting part of the mechanical equipment. This was the first application of this principle, which was expected to yield better utilization of the friction. Earlier tests with coupled axles in a bogie, as on the SNCF locomotives BB–12006 and BB–12043, had shown that the tractive effort could be increased by at least 7% in this way, other conditions remaining unchanged. The torque of the traction motors is transmitted to the axles by a Cardan drive. The gearing of a bogie contains a total of seven gearwheels and pinions. The lower part of the body is in the form of a bridge, bearing the weight, while the lightweight upper part, with the exception of the driver's cabs, can be completely removed. The longitudinal forces between the bogie and the body are transmitted by low-slung links, so as to minimize the reduction of axle load. These links are inclined so that the virtual point of application of the tractive effort to the bogie is approximately level with the top of the rails.

The electrical equipment (Fig. 3) has a number of new design features. The traction motor voltage is controlled on the primary side by means of a high-voltage tap changer. This tap changer was the first to be equipped with a circular, 32-step selector driven by an air motor, which selects the tappings of an auto-transformer. A power transformer reduces the resultant voltage to the value suitable for the traction motors. The load and regulating transformers have radially laminated cores and, as usual, are mounted on the same frame. The weight of the transformer is naturally somewhat

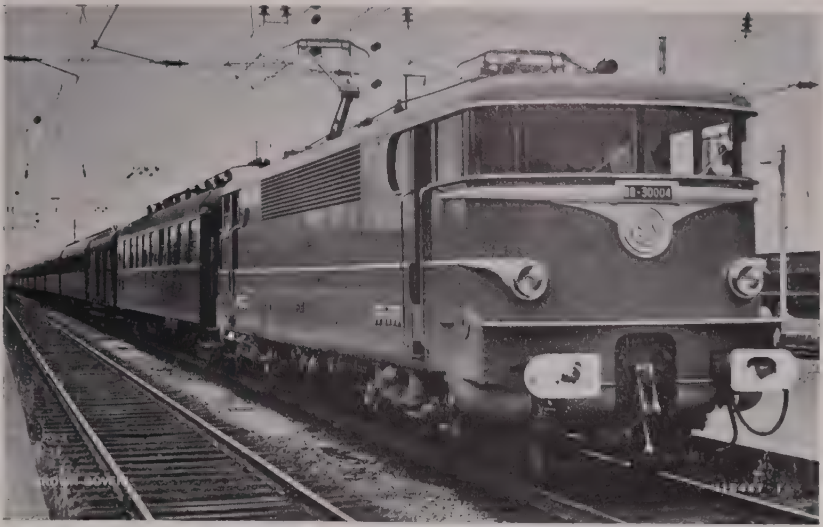

Fig. 2. – Two-frequency locomotive No. BB–20104 (previously BB–30004) of the SNCF, coupled to a 950-t test train in the station at Audun-le-Roman

For these test runs, the locomotive was fitted with bogies for a maximum speed of 160 km/h.

Main data:

Axle arrangement	B'B'	
Voltage:	25 kV 50 c/s	15 kV 16⅔ c/s
One-hour rating (at the motor shafts):	5250 hp (3860 kW)	4150 hp (3050 kW)
One-hour tractive effort at wheel rim:	22·5 t	22·5 t
Corresponding speed:	62·5 km/h	49 km/h
Continuous rating (at the motor shafts):	4880 hp (3590 kW)	3920 hp (2880 kW)
Continuous tractive effort at wheel rim:	20·1 t	20·1 t
Corresponding speed:	64 km/h	51 km/h
Starting tractive effort:	42·5 t	42·5 t
Maximum speed:	105 km/h	105 km/h
Service weight:	84·7 t	

more than that of a pure 50-c/s transformer of the same capacity, despite the power being about 20% smaller when operating at 15 kV and 16⅔ c/s. The oil cooler of the transformer and the smoothing chokes are ventilated by the same fan. Eight air-cooled, single-anode, mercury-arc rectifiers of the excitron type, in Graetz connection, are connected to the low-voltage winding of the load transformer. Each branch comprises two tanks in parallel. Furthermore, there is an equipotential connection between the transformer midpoint and the common point of the two traction motors. The eight rectifiers are arranged in two blocks. An axial fan is fitted underneath each tank.

The two sixteen-pole traction motors are unusually large, and in the course of numerous adhesion tests proved capable of withstanding extraordinary overloads. The starting current sometimes rose to 2·6 times the continuous rating. The remainder of the electrical equipment, in particular the rectifiers, also withstood these currents without suffering any damage. Two air-cooled smoothing chokes, mounted on the same frame, reduce pulsation of the rectified current to an acceptable value.

The auxiliaries are supplied with d.c. from a selenium rectifier, which is connected to a special winding of the regulating transformer with tappings for 50 c/s and 16⅔ c/s. The tap changer has follow-up control, allowing each step to be individually selected. The tests carried out with this locomotive gave unusually interesting results.

For example, adhesion values of 0·50 at a speed of 1 km/h, 0·46 at 20 km/h, and 0·44 at 30 km/h were measured, without sanding. At very high tractive efforts a distinctive oscillation phenomenon was observed, in that, if one axle of a bogie began to slip, this immediately ceased again as a result of the coupling with the other axle but it nevertheless recommenced shortly afterwards. This oscillation persisted until the tractive effort diminished as a result of external influence. Since this phenomenon only arises at unusually high tractive effort and can be successfully countered by special measures, such as using a resilient pinion and the most rigid possible

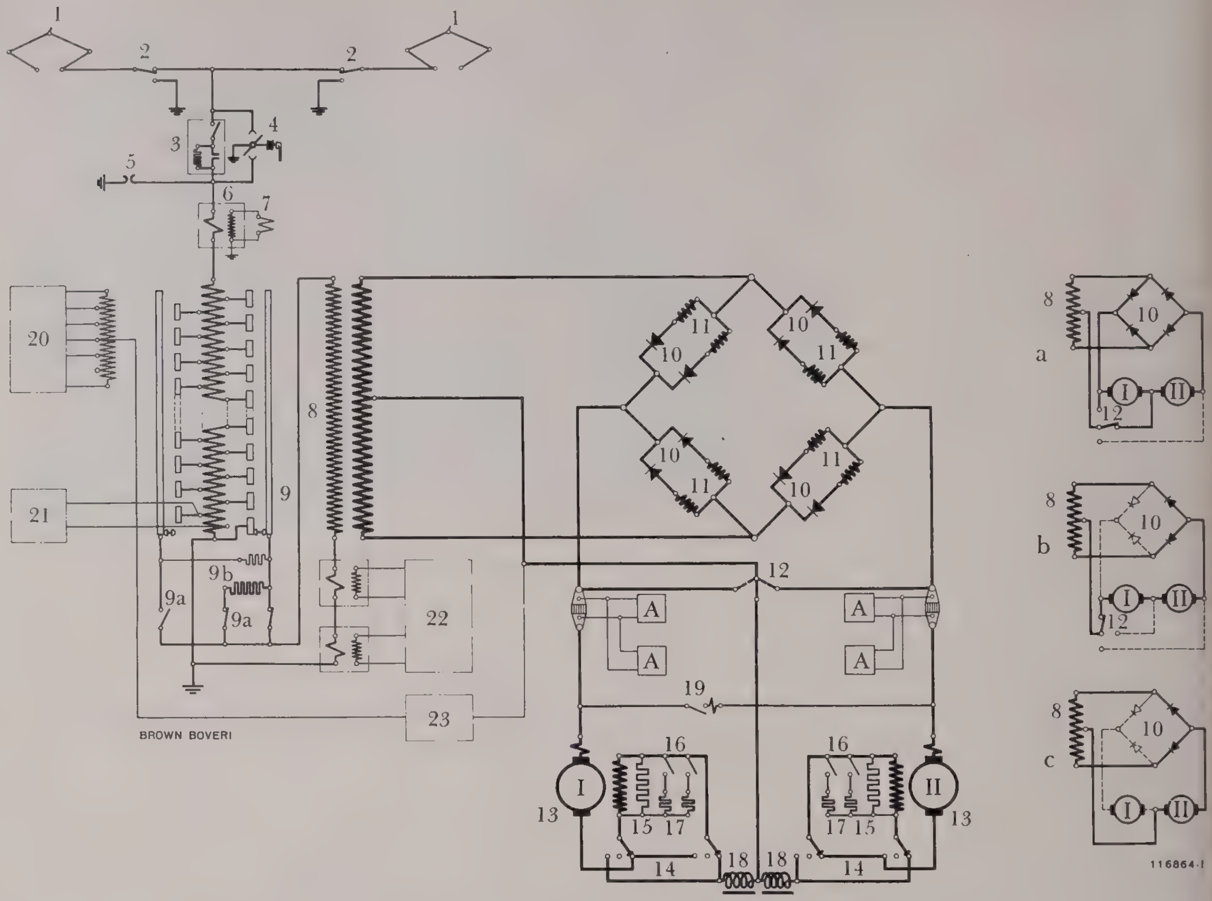

Fig. 3. – Two-frequency locomotive No. BB-20104 (previously BB-30004) of SNCF

Main circuits:

a: Normal operation
b: Operation with only one rectifier block; traction motors in series
c: Operation with only one traction motor
1 = Pantograph-type current collector
2 = Current collector earthing switch
3 = Airblast circuit-breaker
4 = Earthing switch
5 = Arcing horns for overvoltage
6 = Primary current transformer
7 = Overcurrent relay for primary current
8 = Transformer
9 = High-voltage tap changer
9a = Load switch for l.v. tap changer
9b = Diverter resistor
10 = Traction rectifier (single-anode mercury-arc rectifier)
11 = Anode smoothing choke
12 = Changeover link for disconnecting traction rectifiers and traction motors
13 = Traction motors I and II
14 = Reversing switch
15 = Field-weakening resistors, always in circuit
16 = Field-weakening contactors
17 = Field-weakening resistors
18 = Smoothing choke
19 = Contactors for rectifier preheating
20 = Auxiliaries
21 = Train heating
22 = Protection and supervisory equipment for the traction rectifiers
23 = Earth-fault protection

axle drives, higher adhesion values can be obtained in practice with these locomotives than with traction vehicles having individual axle drives. Locomotive No. BB–20104 may thus be loaded in service with 1850 t on a gradient of 1%, whereas the maximum permissible normal load for the locomotives of the 12 000 series, with individually driven axles, is only 1650 t. It is interesting to note that the load of 1850 t on this gradient exactly corresponds to the performance of the six-axle converter locomotive type $C_0'C_0'$ of the series 14 100, weighing 120 t. In the course of tests, trains of 1950 t were repeatedly started up and accelerated to 60 km/h with locomotive No. BB–20104, on a gradient of 1%, without sanding. Summarizing, it may be recorded that, in the case in question, this four-axle locomotive with a total weight of 84·7 t has the same performance as the incomparably heavier six-axle machine weighing 120 t.

This demonstrates what can be achieved nowadays by exploiting all the characteristics of the rectifier locomotive while simultaneously refining the mechanical equipment.

Locomotive No. BB–20103, a sister to the foregoing machine, is equipped with a gear ratio for a maximum speed of 160 km/h. This locomotive can haul express trains weighing 1000 t at a speed of 140 km/h on the flat, and at 90 km/h on gradients of 1%; the SNCF subsequently equipped it experimentally with silicon rectifiers.

Spread of the 50-c/s System

Besides the extensive 50-c/s network of the SNCF, the historic Höllental line of the German Federal Railways, and the section of the Hungarian State Railways between Budapest and Hegyeshalom, lines operating on the 50-c/s system are today in operation or under construction in the following countries:

Turkey, Portugal, the Congo, Great Britain, Japan, India, USSR, and China.

A large number of other countries, of which only Yugoslavia, Finland, Roumania, Bulgaria, Pakistan, and Argentine will be mentioned, are seriously considering the electrification of certain main or suburban lines with single-phase alternating current at 50 c/s. Wherever electrification has been begun, it is being extended as rapidly as finances allow. Two completely different electrification schemes may be quoted as examples of the versatility of the 50-c/s system.

Portugal

At the beginning of 1957 the Portuguese State Railways inau d electric operation on the suburban lin ntra (27 km), and on the Lisbon–Entroncamento section (106 km) of the main line to Oporto. The entire electrification work, which besides the delivery of the rolling stock included the manufacture and erection of all fixed installations, was carried out by a European syndicate of which Brown Boveri is a member. Among the rolling stock delivered were 25 three-coach trains, with single-phase commutator motors, and 15 locomotives with ignitron rectifiers. At the end of 1959, in the course of the extension of electric operation as far as Oporto, a further order was given to the same syndicate for 21 more multiple-unit trains and 20 locomotives.

The multiple-unit trains (Fig. 4) for which Brown Boveri delivered the airblast circuit-breakers, the transformers with radially laminated cores, and the spring drives, each consist of a motor-coach, a middle coach, and a driver-trailer (axle arrangement $B_0'B_0' + 2'2' + 2'2'$). The stainless steel bodies of Budd design were manufactured entirely in Portugal. Up to three multiple-unit trains can be driven from one cab by multiple control. For these trains, which operate as a fixed composition, and whose loading, in contrast to locomotive-hauled trains, varies in relatively close limits, it was permissible to use the simplest circuit arrangement as given by single-phase commutator motors. The main data of these trains [5] are given in the caption to Fig. 4.

The electrification of the suburban traffic in Lisbon was in every respect a success. The traffic soon doubled, and the electric operation is making a substantial contribution to the development of the suburbs. The running time from Lisbon to Sintra, with stops at all stations, was reduced from 57 minutes, taken by steam trains, to 41 minutes. The distance between stations is only about 2 km, and the resultant frequent starting and braking is a severe test on the rolling stock.

India

In order to improve transport facilities between the coal-mining districts of Asansol and Gomoh, the smelting works at Tatanagar, Rourkela and

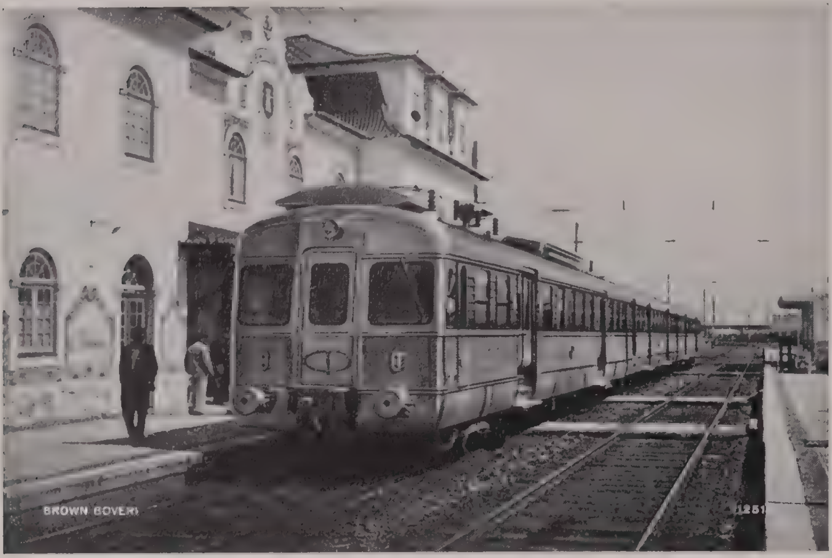

Fig. 4. – Multiple-unit stock of the Portuguese State Railways for 25 kV, 50 c/s in the station at Vila Franca de Xira

Main data:

Voltage of the overhead wire	25 kV 50 c/s
Gauge	1·665 m
Length over buffers of the three-coach trains	71·06 m
One-hour output at the motor shafts	1100 kW
Corresponding speed	63 km/h
Maximum speed	90 km/h
Tare weight	117 t
Number of seated and standing passengers	500

Durgapur, and the ore-producing districts to the south, which had become vitally important as the industrialization of the country progressed, the Indian Railways decided in 1957 to electrify the following lines at 50 c/s: Durgapur–Asansol–Gaya–Moghalsarai of the Eastern Railway, Asansol–Tatanagar–Rourkela and the Raj-Kharsawan–Noamundi branch line of the South-Eastern Railway (see Fig. 5). This decision cancelled earlier projects employing d.c. at 3000 V, with which the electrification of certain suburban lines around Calcutta was already in full swing. High praise is due to the courage and foresight of the Board of Management of the Indian Railways who, in view of the extremely

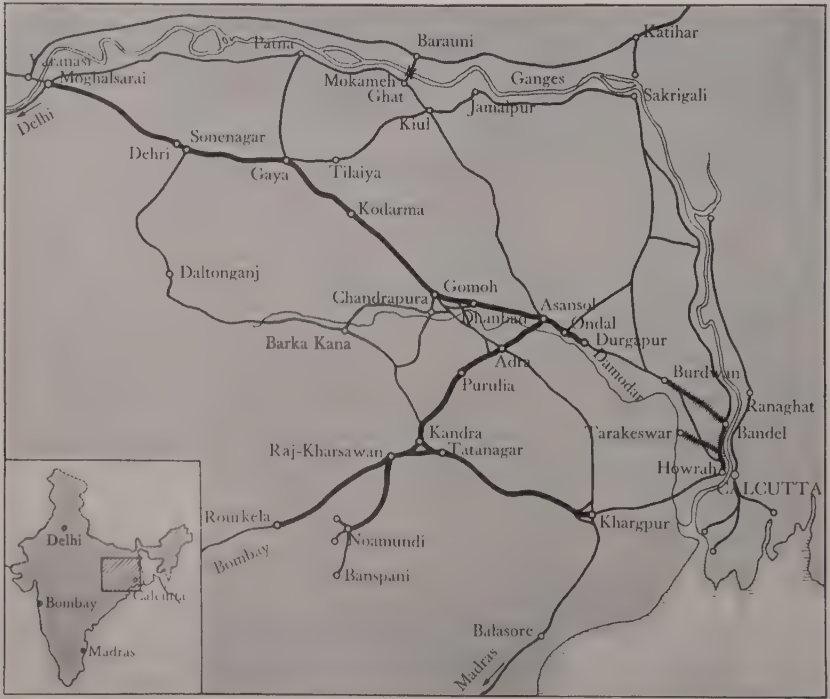

Fig. 5. – Map showing the electrified lines of the Indian Railways in the industrial region west of Calcutta

▬ Lines electrified or in process of electrification at 25 kV, 50 c/s

++++ Lines electrified at 3000 V d.c.

difficult climatic conditions, decided in favour of the new system for these vital lines of communication. At the end of August 1957 an order was placed with the above-mentioned European syndicate for 100 ignitron locomotives with the axle arrangement $B_0'B_0'$, for mixed service. The first machine completed test-runs on an electrified section of the South-Eastern Railway at the end of December 1959 (Fig. 6).

These locomotives have to fulfil the following performance requirements:

- Start up with a trailing load of 2340 t and haul it at 48 km/h up a gradient of 0·5%.
- Start up with trailing load of 3660 t and haul it at 64 km/h up a gradient of 0·16%.
- Haul a trailing load of 685 t (express train) at a speed of 112 km/h on the flat.
- Haul a trailing load of 685 t (express train) at a speed of 72 km/h up a gradient of 1%.

These are therefore typical all-purpose locomotives. In consideration of the relatively high maximum speed of 112 km/h, the total weight had to be kept down to 74·5 t, an exacting requirement for the manufacturers of the electrical and mechanical equipment. The unusually high ambient temperature, up to 50 °C in the shade, made it necessary to design the entire electrical equipment for a temperature rise 20 °C less than permitted by IEC.

For these locomotives Brown Boveri delivered the main circuit-breakers, the high-voltage tap changers with diverter resistors, and the controls for the former, including the master controllers. The current is led via two single-armed current collectors and the main airblast breaker to the low-slung transformer. The voltage is controlled by a high-voltage tap changer with 20 main steps and 20 intermediate steps for continuous loading, on which the air-cooled diverter resistor is in circuit. Each pair of parallel-connected traction motors is fed by two water-cooled ignitrons in push-pull connection, the pulsating current being partly smoothed by a choke. On the other steps, the traction motors can be operated with a shunt across the field windings. In spite of the very high ambient temperature, and the high power of the locomotive, only four rectifier tanks are required, which simplifies the entire equipment.

The three-phase auxiliary system is fed by an Arno converter. Ordinary squirrel-cage motors are used to drive the various fans, the vacuum pumps, and the compressor. Two vacuum pumps are pro-

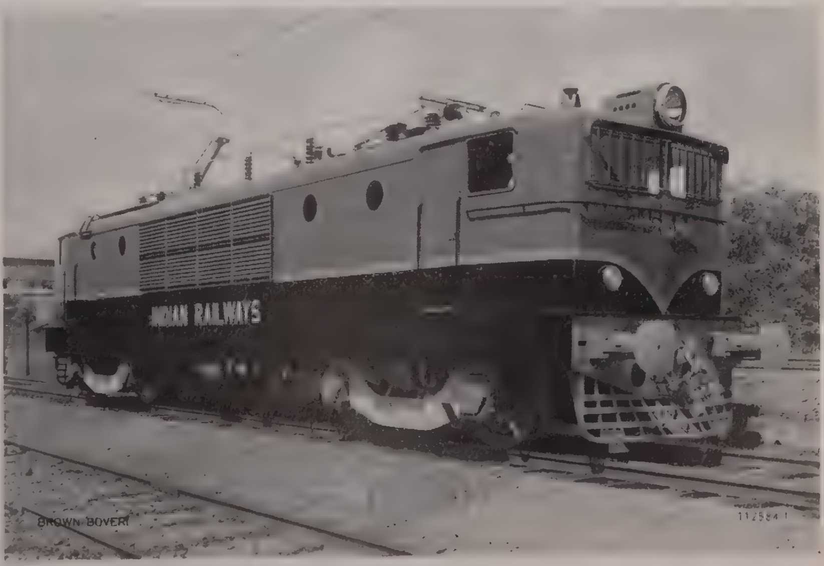

Fig. 6. – Locomotive type BBM No. 20200 of the Indian Railways for mixed duties at 25 kV, 50 c/s

Main data	
Axle arrangement	$B_0'B_0'$
Gauge	1·66 m
Voltage, frequency	25 kV 50 c/s
Continuous rating	2840 hp (2085 kW)
Continuous tractive effort	14·5 t
at a speed of	52 km/h
Maximum speed	112 km/h
Weight of the electrical equipment	32·5 t
Total weight	74·5 t

vided for the operation of the vacuum brakes customarily fitted in India, and a compressor supplies the air for braking the locomotive itself and for the pneumatic equipment. The control gear for the tap changer, manufactured by Brown Boveri, allows the driver to select the positions "–", ".", "+", and "++" on the master controller. On "+", the tap-changer, operated by air motor, switches one step upwards, and on "++" it continues to switch upwards until the driver selects setting ".", or the top step is reached. On setting "–" the tap changer switches downwards. A special control enables the driver to weaken the field of the traction motors in a number of steps. A certain number of the locomotives are equipped for multiple control of two units.

With regard to the mechanical equipment, the design of the bogies is very similar to those on the SNCF locomotives, series 12000. This design is conducive to the attainment of a high adhesion and minimizes the reduction of the load on the foremost axle at high tractive efforts. The torque of the fully spring-mounted traction motor is transmitted to the axles by a Cardan ring arrangement. Particular attention was paid to making the locomotive body water-tight and the maximum tropicalization of the electrical equipment, in view of the heavy continuous monsoon rains which characterize the climate of India in summer and in autumn.

Commissioning of this first hundred 50-c/s locomotives represents merely an initial step and there is no doubt that 50-c/s traction in India will be greatly extended. The Indian Railways are already engaged in the purchase of a large number of locomotives purely for goods traffic, which will be capable of a continuous tractive effort of 22 t, and fitted with electric braking.

Multi-System Traction

Different electric traction systems already meet each other at many points, as a result of the ever-increasing extension of electrified railway networks. This is the case both on international frontiers and in the interior of various countries. An obvious step, in the present trend towards faster and simpler communications, especially in international traffic, is to build traction vehicles which can operate with different types of current. The development of multi-system traction vehicles is one of the most interesting tasks in the field today. If merely different voltages or frequencies are involved without any change in the type of current (e.g. combination of d.c. at 1500 and 3000 V, or a.c. at 15 kV, 16⅔ c/s with 25 kV, 50 c/s), the problems are relatively simple, since in principle the same electrical equipment may be employed.

If on the other hand, a single traction vehicle must be able to operate on both a.c. and d.c. and, furthermore, in each case, at the full power, additional equipment cannot be avoided. As far as the main circuits are concerned, there are in principle two possibilities:

(a) Standard d.c. equipment with starting resistors and an additional "mobile substation", i.e. an untapped transformer and a rectifier set. On a.c. the voltage is controlled by the d.c. controls and the starting resistances, the d.c. simply being taken at constant voltage from the rectifier set instead of from the overhead wire. This solution certainly involves the least expenditure on additional equipment, but it suffers from the disadvantage that no use is made of the economical speed control by means of transformer tappings, usually employed with a.c.

(b) Standard d.c. equipment and, in addition, standard a.c. controls, i.e. a tapped transformer with a tap changer or bank of contactors, and a rectifier set, supplied with the regulated voltage. This solution, although involving additional outlay, is adopted if operation is mainly in the a.c. system.

For both variants, the traction motors must naturally be suitable for pulsating current and, depending on the design of the motors, it may also be necessary to use smoothing chokes for a.c.operation.

A third possibility would be to use single-phase a.c. commutator motors, together with both a.c. and d.c. controls. It is well known that these motors can also be operated with direct current. Owing to the fact that the terminal voltage of the motors has to be limited to a few hundred volts at 50 c/s, problems arise when this solution is used with direct current at high voltage, for example 3000 V, since it involves connecting a number of motors permanently in series.

The auxiliaries may conveniently be operated on alternating current. In this case the alternating current is generated by a d.c.-a.c. converter, whose driving motor is fed direct from the overhead wire on d.c., and from a rectifier on a.c. supplies. This may be the traction rectifier, provided its voltage is constant and provided the d.c. control gear is also used for a.c. operation. The weight and dimensions of such converter sets are, of course, not inconsiderable.

Multi-system traction vehicles are equipped with system selector devices, which ensure that the correct connections are established for the type of current which is being supplied, and exclude faulty operation on the part of the driver. The collection of the current from the overhead wire is a further problem. The various railway authorities have their own clearances and contact-wire standards, which must be taken into account, so that a multi-system traction vehicle may have to be equipped with up to four current collectors, each of which is intended for a particular traction system or railway administration.

Multi-system traction vehicles, for a variety of types of current, will always involve additional weight and cost, which may become quite considerable, depending upon the requirements.

Three examples of Brown Boveri activity in the field of multi-system traction vehicles are described below:

Two-Frequency Shunting Locomotives of the Swiss Federal Railways, Series Ee 3/3^{II}

These units, commissioned in 1957, and built for 15 kV, 16⅔ c/s, and 25 kV, 50 c/s, have the following main characteristics [6]:

One-hour rating at the motor shaft	710 hp (520 kW)
Corresponding speed	26·5 km/h
One-hour tractive effort at the wheel rim	7100 kg
Maximum starting tractive effort at the wheel rim	13 800 kg
Maximum speed	45 km/h
Total weight	45 t

They are of the rectifier type, with radially laminated transformer, l.v. tap changer with 28 steps, and two single-anode pumpless air-cooled mutators in push-pull. The smoothed, pulsating current is fed to a single traction motor. The auxiliaries are driven by d.c. motors, fed from a dry-type rectifier. The batteries are charged by a similar static rectifier unit.

In operation at 25 kV, 50 c/s, the connection of the traction winding of the transformer is not altered, but the tap changer is prevented from going above the 18th step, to limit the motor voltage to the highest permissible value. The auxiliary supply winding of the transformer, on the other hand, has tappings for operation both at 15 kV, 16⅔ c/s, and 25 kV, 50 c/s.

The mechanical equipment of these locomotives corresponds to that of the well-known shunting locomotives No. 16381–16430, belonging to the Swiss Federal Railways, in service in the international railway junction at Basle.

Triple-System Locomotive Belonging to the Swiss Federal Railways, Series Ae 4/6^{III}

This is a conversion of the world's first gas-turbine locomotive, which was commissioned in 1941. As a thermal locomotive, and the only one of its type, it was no longer economical on the fully electrified network of the Swiss Federal Railways. In converting it to a triple-system traction vehicle for 15 kV, 16⅔ c/s; 25 kV, 50 c/s, and 1500 V d.c. the main frame, the bogies, and the traction motors were retained. The greater part of the locomotive body was rebuilt in the Zurich workshops of the Swiss Federal Railways, and a block, containing the following components, was fitted on a special frame of its own, in place of the gas turbine:

For a.c. operation:

Transformer with built-on high-voltage tap changer for 32 steps, silicon rectifier (not of our manufacture), consisting of four blocks in Graetz connection, accommodated in two housings, each connected to one traction motor, and smoothing chokes.

For d.c. operation:

Starting resistors, of the compact vane type together with the associated fans and cam-operated switchgear.

The reversing and system changeover switches are in use for both types of operation (Fig. 7). Separate a.c. control equipment was provided, in view of the fact that the locomotive operates mainly on this supply. At 25 kV, 50 c/s, the tap changer is prevented from going above the 22nd step, to avoid exceeding the permissible motor voltage. The self-ventilated traction motors, fitted in the gas-turbine version, were retained without alteration. One of the two current collectors is intended for d.c., and the other for a.c. at 15 and 25 kV. When running on a.c. the d.c. input is earthed by a system isolator. A special silicon rectifier feeds the auxiliaries with direct current at 180 V during a.c. operation, while for d.c. operation they are connected to a converter set (1500 V/180 V). This most interesting traction vehicle is, to our knowledge, the first triple-system locomotive in the world, and at the same time represents the first application of the silicon rectifier to traction in Switzerland. The main characteristics of this unit are:

Current types	15 kV, 16⅔ c/s 25 kV, 50 c/s 1500 V d.c.
One-hour rating at the motor shafts	2400 hp (1760 kW)
Corresponding speed	79 km/h
One-hour tractive effort at the wheel rim	7 850 kg
Maximum starting tractive effort	14 700 kg
Maximum speed	110 km/h
Weight of the electrical equipment	appr. 40 t
Total weight	appr. 85 t

Two-System Multiple-Unit Stock of the Italian State Railways

These trains consist of a normal $B_0'B_0'$ motor-coach for 3000 V d.c. and a driver-trailer with built-in rectifiers. The latter allow the train to run on alternating current at 3300 V, $16^2/_3$ c/s.

The motor-coach has the normal d.c. equipment, with a one-hour rating of 1030 hp (760 kW) at 73·5 km/h and a maximum speed of 150 km/h, while the rectifier sets housed under the floor of the driver-trailer consist in essence of the main circuit-breaker, the dry transformer with a continuous rating of 545 kVA, and six air-cooled, pumpless single-anode rectifiers, in three-phase Graetz connection, together with the corresponding current collectors. The direct current is delivered at 3000 V and is fed to the traction vehicle through a heating jumper. The equipment is dimensioned so that a third coach can be attached. These three-car units, sometimes operated under multiple control in larger trains, run on the lines between Milan, Voghera, Genoa and Turin. In all, twelve units with Brown Boveri rectifiers are in operation, the first two having been in service since 1958.

Prospects to Future Development

Within the short space of 10 years, the 50-c/s system has developed into an economic, high-performance railway traction system. In view of this rapid progress it is justifiable to ask whether this system has not already reached the peak of its importance, especially as its growth took place at a time when many components of other traction

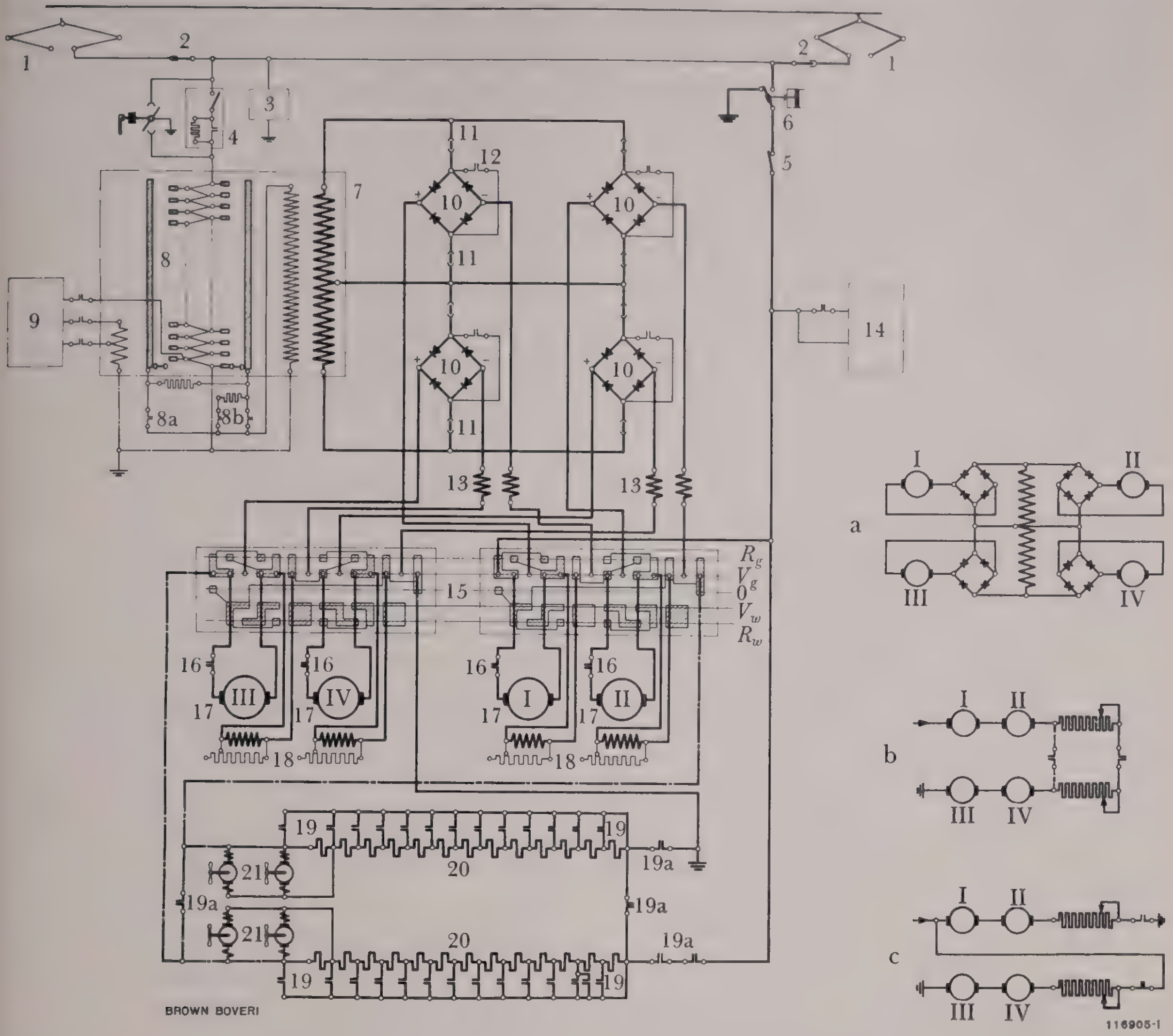

Fig. 7. – Triple-system locomotive series Ae 4/6 ^{III} of the Swiss Federal Railways (SBB)

Main circuits:

a: A.C. operation
b: D.C. operation (series connection)
c: D.C. operation (parallel connection)

1 = Current collector
2 = Current collector isolating switch
3 = System-selector equipment
4 = Main circuit-breaker for alternating current 16⅔ c/s and 50 c/s
5 = Main circuit-breaker for direct current 1500 V
6 = System isolating switch
7 = Transformer
8 = High-voltage tap changer
8a = Load switch for h.v. tap changer
8b = Transfer resistor
9 = Train heating and auxiliaries (a.c.)
10 = Traction rectifiers (silicon)
11 = Disconnecting link for traction rectifier
12 = Shorting switch for traction rectifier
13 = Smoothing chokes
14 = Train heating and auxiliaries (d.c.)
15 = Reverser and system changeover switch with the following positions:
R_g = Reverse, d.c.
V_g = Forwards, d.c.
0 = Neutral
V_w = Forwards, a.c.
R_w = Reverse, a.c.
16 = Motor isolating contactor
17 = Traction motors I–IV
18 = Field-weakening resistors, always in circuit
19 = Cam-operated d.c. switchgear
19a = Grouping switches
20 = Starting resistors
21 = Fans for starting resistors

systems had already reached a high state of development.

In reality, the new system is only at the beginning of a world-wide development. The experience gained from the increasingly rapid extension of the 50-c/s railway networks will in future make it even easier than hitherto, to minimize not only the initial cost of the traction vehicles and their components, but also the maintenance and operating costs. To this purpose, efforts will constantly be directed towards finding simpler solutions.

A certain uncertainty in predictions about future technical development is naturally inevitable, since it is inherent in all development that problems must be dealt with, whose solution is initially unclear. It is especially difficult to make such predictions in the field of railway traction, since the exploitation of new possibilities in this field is subject to special obstacles and restrictions in respect of weight, space requirements, and operating conditions. An attempt will nevertheless be made, in full awareness of the attendant difficulties, to sketch some aspects of such development. The lines of development are generally valid for the traction vehicles and are applicable to any system.

As far as the mechanical equipment is concerned, the single-motor bogie will undoubtedly find further acceptance wherever conditions require the greatest utilization of the adhesion, and it is conceivable that its design may be made still lighter and cheaper. Gearing with two different ratios, selected when the vehicle is at a standstill, has already been used on the SNCF locomotives of the 16500 series [7]. Speed-change gearing which may be selected while the vehicle is in motion is technically feasible, but has not been found necessary.

Synthetic materials are finding ever wider application for non-stressed mechanical components, for example as in some of the latest locomotives of the SNCF and British Railways. This reduces weight and maintenance.

In the electrical sector, practically every component may be expected to undergo a long period of development. It is fundamentally desirable to replace rotating auxiliary machinery by static equipment. The rectifier, which has displaced the converter set, is the most striking example of this. The substitution of dry-type rectifiers (equipped in some case with transductor or transistor control) for charging dynamos and exciters, may be advantageous and is making rapid progress.

One of the most immediate and important steps, which has already been taken in respect of certain prototype locomotives, is the replacement of the mercury-arc rectifier by semiconductors, chiefly silicon diodes. Not only does this eliminate the extensive igniting and excitation gear, but it also substantially simplifies the cooling, since, in the case of silicon cells, it is only the upper temperature which is limited, whereas the operating temperature of mercury-arc tanks must generally be kept within certain limits, i.e., both cooling and heating are required. Silicon rectifier sets are also considerably lighter, for the same output, than all other known types of rectifier. The very low thermal time constant of silicon diodes, and the protection of the cells against overcurrent and overvoltage present difficult problems, which are, however, in process of being overcome. High-output semiconductor diodes still suffer from the disadvantage that they cannot be controlled, in contrast to ignitron and excitron rectifiers, and thus cannot be employed as inverters, for example in regenerative braking. However, with modern braking resistors, it is possible to achieve a very powerful rheostatic braking system with modest weight and space requirements. Brown Boveri have always occupied a leading position in the rectifier field and are also actively participating in the development of silicon rectifiers and their accessories.

The exploitation of the possibilities of modern materials will permit further progress in the construction of transformers. The insulating and cooling media most suited to the state of development of the technique must also be sought. In the field of voltage regulation, the trend will be towards eliminating contacts in the tap changers, as far as possible, or at least, towards transferring the functions of the load switches, which are subject to the greatest wear, to elements of the transductor type. Here, too, the tendency is to replace equipment containing moving parts by purely static components, but not overlooking the aspects of weight and space requirements.

In the course of the same general trend the numerous relays and control solenoids found in a traction vehicle will be increasingly replaced by contactless transistorized elements, especially at points where heavy wear must be expected. Promising beginnings have been made, especially in respect of the control of the tap changers. As already mentioned in a number of places in the literature, it has been found that it is not always advantageous simply to replace individual solenoids and contacts by transistor elements while retaining the same circuit arrangements. It will, therefore, inevitably be necessary to review the entire conception of a traction vehicle, with respect to the circuits, and to redesign it from scratch, giving due regard to the inherent characteristics of modern contactless elements.

In conclusion, it must be emphasized that, wherever an extensive 16⅔-c/s railway network already exists, the continued development and expansion of this well-tried system is the only correct course. During the 50 or more years since its inception this system has been found to offer a convenient solution to every traction problem.

In view of the success achieved with 50-c/s traction, best illustrated by the performance of SNCF locomotive No. BB-20104, described on pages 586–9, it is worth investigating whether the experience gained cannot be applied to a greater extent than hitherto to the classic 16⅔-c/s system. We have in mind particularly the use of rectifiers and the principle of the single-motor bogie, the combination of which offers the best possible exploitation of the friction between rail and wheel.

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DIESEL-ELECTRIC TRACTION

621.335–833.6

The Brown Boveri concern has contributed to the development and construction of various modern diesel-electric vehicles. The following article gives a general survey of these new locomotives and motor-coaches.

DURING the course of the last few years the administrations of a number of European railways have had locomotives from 1300 to 1500 hp designed and built by means of industry in their own countries. These railway vehicles compare approximately with the type "f", as designed by ORE.[1] Brown Boveri are taking part in the construction of locomotives with electrical transmission, principally in France, Italy, and Austria.

Prototype locomotives are presently being built in Austria for the Austrian Federal Railways. The machines, which weigh 70 tons and have the axle sequence $B'_0B'_0$, have the following characteristic data:

Diesel engine output	1435 hp
Diesel engine manufacturer	Daimler-Benz
Peak tractive effort at wheel rim on starting	22 700 kg
Continuous tractive effort at wheel rim	11 800 kg
Equivalent speed	25·8 km/h
Maximum speed	100 km/h
Length over buffers	16·24 m

The main generator, which is directly coupled to a diesel engine running at 1500 rev/min, feeds the four traction motors, these being series-parallel connected. A 75-hp diesel engine, combined with a compressor, serves as a drive for the auxiliary generator. This generator is used to excite the main generator, for recharging the batteries, and as current supply for the various auxiliary motors, the lighting, and so on. The traction motor fans and cooling ventilator of the diesel engine are hydrostatically driven. For heating purposes the locomotive was fitted with a boiler, which is included in the total weight of 70 tons. The electrical equipment was delivered by the Brown Boveri works in Vienna, Austria, whereas the mechanical part was manufactured by Simmering, Graz, Pauker, Vienna.

In France and Italy a number of different locomotive series have been built and some of these are already in service. The French National Railways (SNCF) have to date awarded contracts for a total of ninety series 040 DG diesel-electric locomotives. These machines have the axle sequence $B'_0B'_0$, with an output of 1200 to 1750 hp, each having a built-in diesel engine (Fig. 1). The principal data of these vehicles are found below:

Diesel engine output	hp	1 200	1 400	1 750
Diesel engine manufacturers[2]		SGCM	MGO	Sulzer/ CCM
Peak tractive effort at wheel rim on starting	kg	20 400	20 400	17 700
Continuous tractive effort at wheel rim	kg	13 000	13 000	12 000
Speed at continuous output	km/h	18·2	21·6	29·4
Maximum speed	km/h	105	105	120
Total service weight	t	72	72	72

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[1] Office de Recherches et d'Essais de l'Union Internationale des Chemins de Fer.

[2] SGCM = Société Générale de Constructions Mécaniques, La Courneuve
MGO = Mareb-Grosshans-Ollier, Mulhouse
CCM = Compagnie de Constructions Mécaniques, Procédés Sulzer, Paris

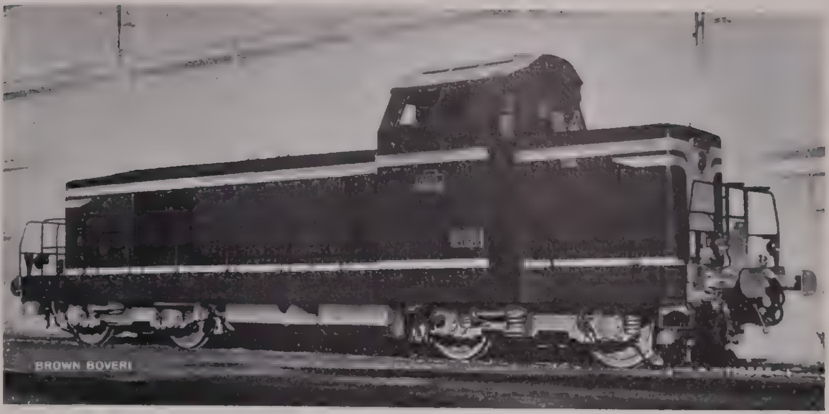

Fig. 1. – Diesel-electric locomotive series 040 DG operated by Société Nationale des Chemins de fer Français (SNCF)

This $B_0'B_0'$ type locomotive has an output of 1400 hp and develops a tractive effort at the wheel rim of 13 000 kg at 21·6 km/h. (Supplied by Compagnie Electro-Mécanique, CEM, Paris.)

With the exception of the traction motors and reversing switches, all the material for these vehicles was supplied by our associate company, Compagnie Electro-Mécanique (CEM) in Paris. The main and auxiliary generators, as well as the switchgear, the regulating and the control gear, were included in the delivery. The locomotive, which is equipped with one control cab, provides the driver with excellent vision. The four traction motors, which operate in parallel, are fed through a Brown Boveri servo-field regulator by an automatically regulated main generator. All the auxiliary equipment, such as auxiliary generator, compressor, and ventilator, are driven mechanically by Cardan shaft and belt drives.

The Italian State Railways have bought 20 type $B_0'B_0'$ (Fig. 2) locomotives, which they developed together with Italian industry. These locomotives have two control cabs, and the following technical data:

Diesel engine output	1 320 hp at 1 000 rev/min
Diesel engine manufacturer	Fiat, Turin
Peak tractive effort at wheel rim on starting	18 900 kg
One-hour tractive effort at wheel rim	8 900 kg
Speed at one-hour output	28 km/h
Maximum speed	100 km/h
Total service weight	64 t

For the above mentioned vehicles Brown Boveri, Baden, delivered the turbochargers and Tecnomasio

Fig. 2. – Diesel-electric locomotive series D 341 operated by the Italian State Railways

This locomotive has an output of 1320 hp and develops a one-hour tractive effort of 8900 kg at 28 km/h. (Supplied by Tecnomasio Italiano Brown Boveri, Milan.)

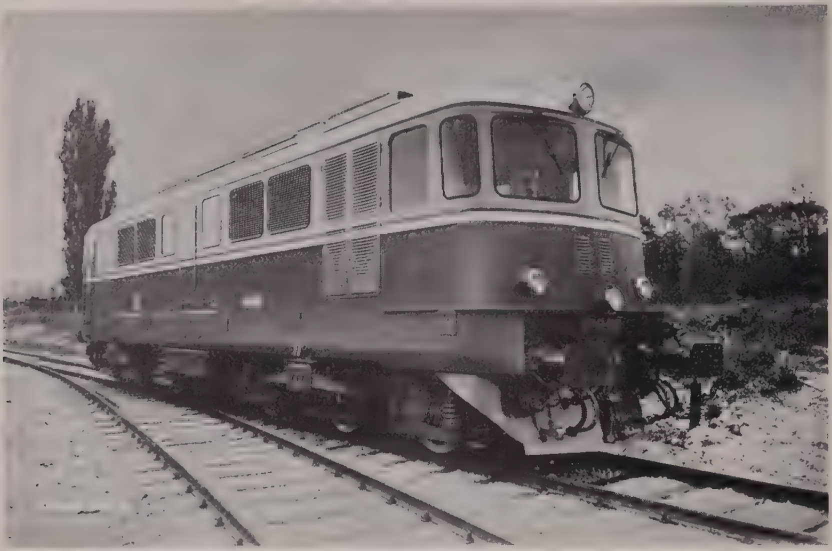

Fig. 3. – Diesel-electric locomotive type 060DA owned by the Roumanian State Railways, with an output of 2100 hp and a continuous tractive effort of 20 000 kg at 21·5 km/h

Italiano Brown Boveri, Milan, supplied the traction motors and a part of the mechanical equipment. The Italian State Railways have decided recently to procure an additional series of 85 similar locomotives, some of which, however, are to have an output of 1400 hp and a top speed of 110 km/h.

In the last few years the increased need for locomotives with outputs of approximately 2000 hp has been experienced for hauling heavy freight trains. Brown Boveri have collaborated very actively in the development and construction of such traction vehicles. Typical examples are the locomotives for the Roumanian and Finnish Railways.

The 6-axle, 2100 hp, type $C_0'C_0'$ locomotives for the Roumanian State Railways (Fig. 3) [1, 2][3] are the combined product of the Swiss Locomotive and Machine Works, Winterthur, for the mechanical part; Sulzer Bros., Winterthur, for the diesel engines, and Brown Boveri, Baden, for the electrical equipment. The important technical data are:

Track gauge	1·435 m
Length over buffers	17 m
Body width	3 m
Peak tractive effort at wheel rim on starting	32 000 kg
Continuous tractive effort at wheel rim	20 000 kg
Speed at full load	21·5 km/h
Top speed	100 km/h
Total service weight	114 t

The first six locomotives were completely built in Switzerland. Another ten machines will have the electrical equipment and diesel engines produced in Switzerland, while the mechanical part will be built under licence in Roumania. Roumanian industry will later build large series of this type of locomotive under licence from the above-mentioned Swiss companies. Fabrication of such machines has already begun, and it is expected that the first locomotive completely produced in Roumania can be put into service in the course of 1961.

In Finland thirty-two 1900-hp diesel-electric locomotives of the Hr 12 series are presently in operation or being built. These locomotives were developed by the following companies:

Mechanical part:	Swiss Locomotive and Machine Works, Winterthur
Electrical equipment:	Brown Boveri, Baden
Diesel engines:	Maschinenfabrik Augsburg-Nürnberg AG. (MAN), Augsburg

At the beginning Swiss and German industry split the manufacturing of these locomotives; however, even while the first series was being built,

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[3] The figures in brackets refer to the bibliography on p. 604.

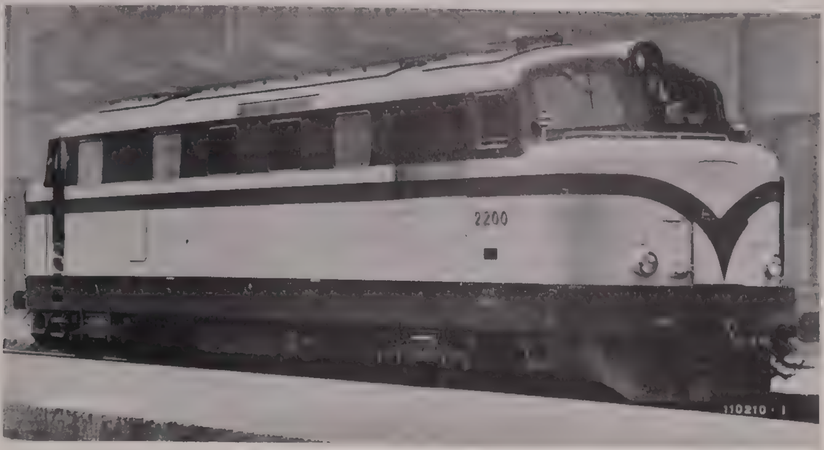

Fig. 4. – Diesel-electric locomotive, type Hr 12, operated by the Finnish State Railways, with an output of 1900 hp and a continuous tractive effort of 12 000 kg at 32 km/h

Finnish industry took a very active part. Today the Finnish firms Valmet, Lokomo, Tampella, and Strömberg have taken over the manufacture of these locomotives under licence. Now they import only a few items of special apparatus. The important data for the locomotives are:

Track gauge	1·524 m
Length over buffers	18·5 m
Body width	3·2 m
Continuous output of diesel engine	1 900 hp
Speed of diesel engine	900 rev/min
Peak tractive effort at wheel rim on starting	32 000 kg
Continuous tractive effort at wheel rim	12 000 kg
Speed at full load	32 km/h
Maximum speed	120 km/h
Weight of mechanical parts (together with boiler for heating the coaches)	66 t
Weight of diesel engine	20·5 t
Weight of electrical equipment	27 t
Additional extra weights	6·5 t
Total service weight	120 t

The main generator, which is controlled by a Brown Boveri servo field regulator, feeds three parallel groups of traction motors, each with two in series. The locomotives are equipped with automatic field weakening. Brown Boveri spring drives transmit the torque of the motors to the driving axles.

With the continuous and extraordinary increase in passenger and freight traffic the outputs of locomotives such as those described above are, in general, too small today. Thus, efforts are being made to develop six-axle diesel-electric locomotives with outputs of 3000–3500 hp, and more. These studies bring up difficult problems, principally concerning the weight distribution. The pressure of 20 tons per axle may not be exceeded, and in some cases is limited to 19 tons. Sometimes the solution of using one diesel set may be employed, depending on the economics involving weight and price. Consequently, the diesel engine designer must construct engines with greater output at relatively higher speeds. He must be able to guarantee them for absolute dependability, the longest possible life, and the least amount of maintenance.

For the electrical designer, the construction of fast-running generators with higher outputs is only possible when the latest technical knowledge and the most modern materials are employed, particularly for insulation. Also, the designer of the traction motors and the generator must carefully balance the important factors, such as voltage, current, and degree of field weakening, in order to obtain the optimum conditions relative to total weight, while maintaining full reliability. As for all-electric locomotives, the coefficient of rail friction can be utilized to its utmost limit through the use of suitable motor connections and proper axle drives. Likewise the co-operation with the mechanical designer permits the weight of the mechanical section to be kept at the lowest possible value. Such high-powered locomotives, which are presently being studied and which possess all the advantages regarding electrical transmission, will thus be vitally important to railway managements and permit them to meet continuously growing operational requirements.

Besides high-powered locomotives, every railway system has a need for traction vehicles for shunting or light freight duty. With this in mind the Italian State Railways, with the help of credit from Eurofima,[4] have ordered 29 diesel-electric locomotives with outputs of 600 hp each. These locomotives, which were developed by Brown Boveri, will be built by our associated company in Milan, in co-operation with the Breda Works (also situated in Milan). The main technical data for these vehicles are:

Continuous output of diesel engine	700 hp
Speed	1500 rev/min
Diesel engine manufacturers	Daimler-Benz/ Fiat
Length over buffers	13 m
Body width	3 m
Peak tractive effort at wheel rim on starting	19 000 kg
Continuous tractive effort at wheel rim	12 000 kg
Speed at full load	11 km/h
Maximum speed	80 km/h
Total service weight	64 t

These locomotives possess a single, centrally located, raised driver's cab, which affords a good view in all directions. The control of the vehicle is very simple. A single lever is employed for "driving" and "braking" and a separate lever for reversing the direction of motion. Since the driver of one of these vehicles does not need to pay atten-

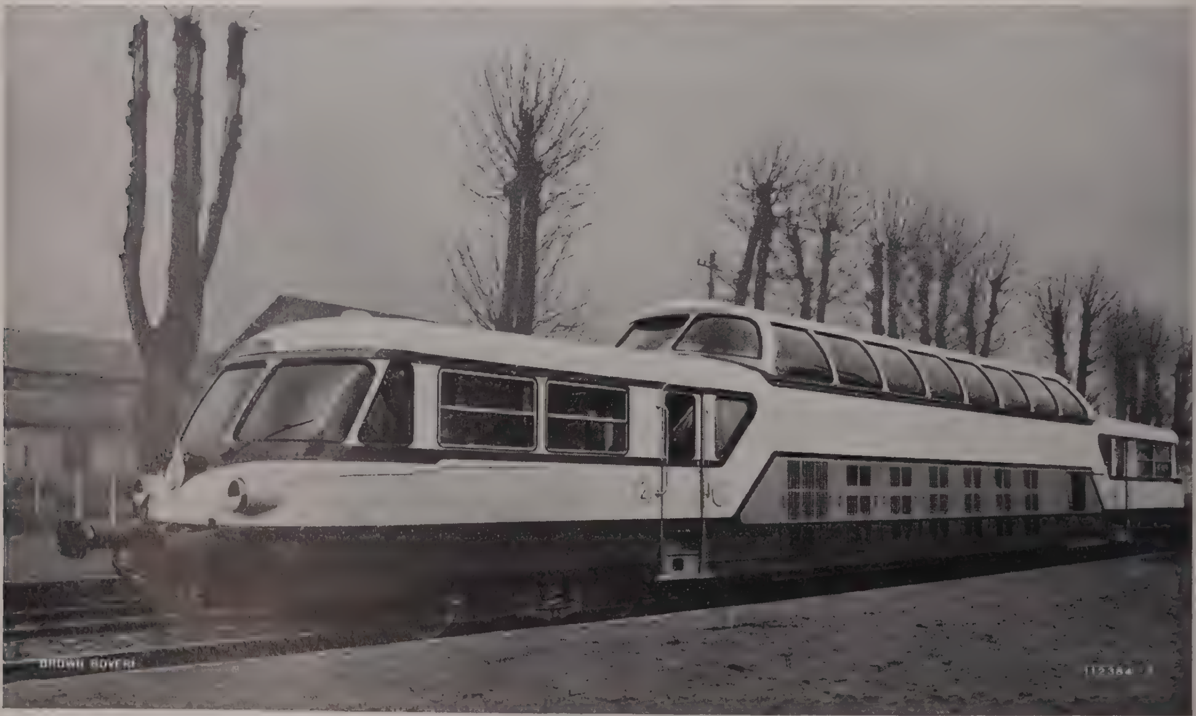

Fig. 5. – Diesel-electric motor coach, known as "Autorail panoramique", operated by SNCF

Output 800 hp, continuous tractive effort 2800 kg at 52 km/h. Maximum speed 130 km/h. (Supplied by CEM.)

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[4] European Rolling-Stock Finance Company, Basle.

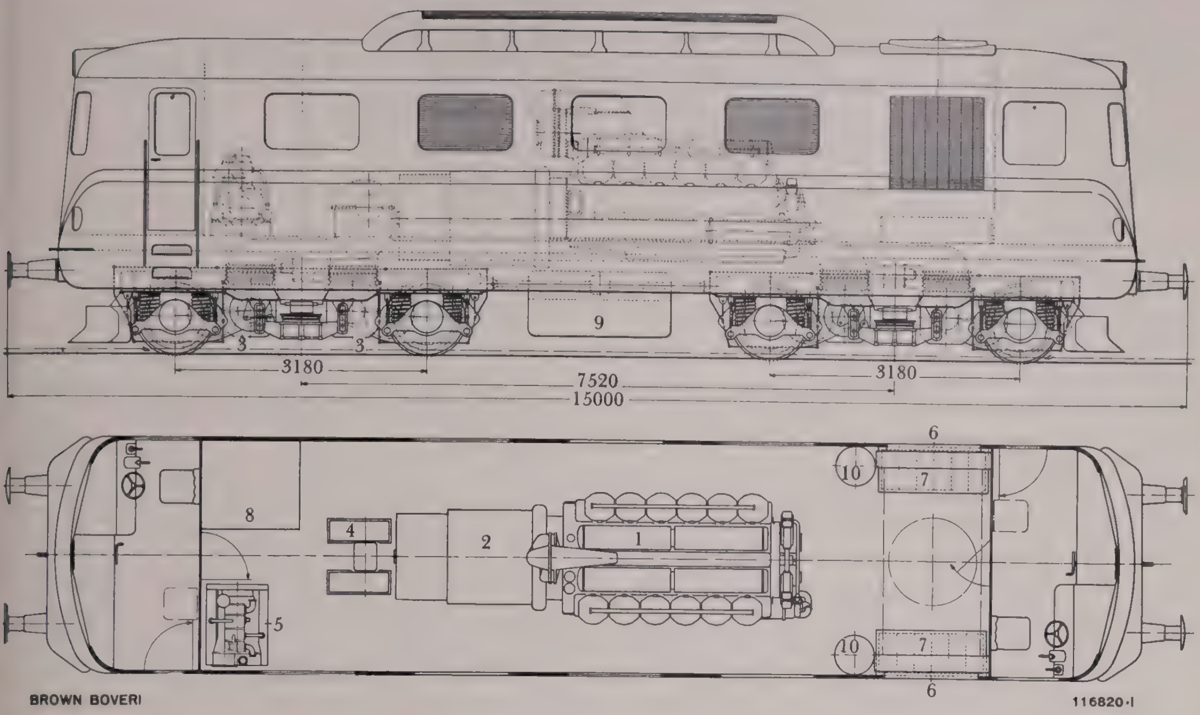

Fig. 6. – Diesel-electric rack and adhesion locomotive type $B'_u B'_0$, output 1300 hp

1 = Diesel engine
2 = Main and auxiliary generator
3 = Traction motors
4 = Fan set
5 = Compressor set
6 = Water and oil coolers
7 = Storage battery
8 = Electrical apparatus
9 = Fuel tank
10 = Main air receiver

tion to instruments or to any other apparatus, he can devote his full attention to the line and the signals, which is extremely important in shunting.

The four motors, which are fed by the main generator, are series-parallel connected and cooled by an electrically driven fan. The compressor and cooling pump motor are mechanically driven. The main generator excitation is automatically controlled by a Brown Boveri servo field regulator.

Worth mentioning is an order from the RENFE (Red Nacional de los Ferrocarriles Españoles) for 50 diesel-electric locomotives type C with outputs of 350 hp each. The electrical equipment for the locomotives will be delivered by Brown Boveri, Baden. A share of the contract has been given to a Spanish licensee, Maquinista Terrestre y Marítima, Barcelona, who are producing the diesel engines and some of the mechanical equipment. The principal technical data for the locomotives are as follows:

Track gauge	1·676 m
Length over buffers	9·8 m
Peak tractive effort at wheel rim on starting	14 000 kg
Continuous tractive effort at wheel rim	6 400 kg
Speed at full load	10·5 km/h
Maximum speed	45 km/h
Total service weight	48 t

Also interesting are the ten high-powered diesel-electric motor-coaches which have recently been delivered to the French National Railways (SNCF). The CEM, in co-operation with Renault, designed and built these locomotives. The "Autorails panoramiques", as they are generally called, have an output of 800 hp. The middle part of the car is raised and offers the passengers an excellent view. The diesel-electric set can be placed between the bogies under the raised middle section. The important data for these diesel-electric coaches are:

Diesel engine output	800 hp
Diesel engine manufacturer	MGO
Length over buffers	27·77 m
Seating capacity 1st class	44
,, ,, 2nd class	44
Peak tractive effort at wheel rim on starting	7 000 kg
Continuous tractive effort at wheel rim	2 800 kg
Speed at full load	52 km/h
Maximum speed	130 km/h
Total service weight	55 t

Finally, we would like to mention the latest application of diesel-electric traction to rack railways. At present the Brown Boveri concern is studying and building several such vehicles (Fig. 6). The main characteristics of two extreme types are as follows:

Nominal output	hp	1300	200
Track gauge	mm	1435	1435
Steepest gradient	%	7	11
Nature of service		freight and passenger trains	shunting
Axle sequence		$B_0'B_0'$	B_0
Total service weight	t	70	23·8
Diesel engine output	hp	1 300	200
at a speed of	rev/min	1 000	2 000
Peak tractive effort at wheel rim	kg	23 000	18 300
Continuous tractive effort at wheel rim	kg	13 100	8 500
Corresponding speed	km/h	19·2	4·5
Maximum speed			
on adhesion sections	km/h	60	30
on rack sections	km/h	25	15
Brakes		electrical	electrical

In the field of traction we see rich future possibilities for the application of electrical transmission, which not only guards the diesel engine against all overloads but also, without any difficulties, permits reliable electrical braking.

(JRI) A. FEDDERSEN

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ELECTRICAL TRANSMISSION FOR DIESEL VEHICLES

621.335-833.6

The properties and advantages of the electrical transmission of the power of diesel engines to the driving axles of a diesel-electric rail vehicle are discussed in the present article. The dual-characteristic method, as it is called, which is prominent among a number of methods of controlling the power, allows full benefit to be gained from the output of the diesel engine over a wide working range, in that one characteristic is designed to produce a high tractive effort on starting, while the other enables the vehicle to attain a high speed. For high outputs, control by means of the Brown Boveri system of servo-field control has given good results.

General Remarks Regarding Electrical Transmission

ON ACCOUNT of the unfavourable behaviour of the diesel engine when running, it is not always possible to transmit its power direct to the driving axles of a rail vehicle, or at least it is uneconomical. The electrical method of transmission makes it possible for the power of the diesel engine, or its unsuitable torque characteristic, to be adapted to the requirements of railway traction. It completely fulfils these requirements, while gaining full benefit from the output of the diesel engine, yet imposing no undue stresses upon it.

The elements of the transmission system may be split into the two following groups:

the current generator
the traction motors.

With electrical transmission the following advantages are gained:

Very simple operation.

Smooth starting without any shock.

Starting with full torque from standstill.

High starting tractive effort without overstraining.

The speed is automatically adapted to the tractive effort with varying load and gradients, while maintaining constant output from the diesel engine.

The diesel engine can be run in the most suitable speed range, enabling it to achieve a low fuel consumption and long life.

For the electrical power transmission a main generator is coupled to the diesel engine, and by specially arranging its characteristic or by employing a suitable control system, it can feed the traction motors with variable voltage and current, depending on the speed or tractive effort required. The various auxiliaries are fed by an auxiliary generator, the armature of which is driven by belts in some cases, but which is mounted on the main shaft in the majority of cases.

Dimensioning the Output of the Main Generator

The dimensions and weight of the main generator are determined for a given speed of the diesel engine by the following factors: The starting and one-hour currents of the traction motors, and the maximum voltage corresponding to the upper speed limit at which full advantage should be taken of the output of the diesel engine. It is therefore evident that the size of the generator is not necessarily governed by the output of the diesel engine, but that it varies with the haulage conditions of the train, particularly being governed by the trailing load and the running speed. The one-hour and continuous current ratings determine the temperature rise in the armature. For

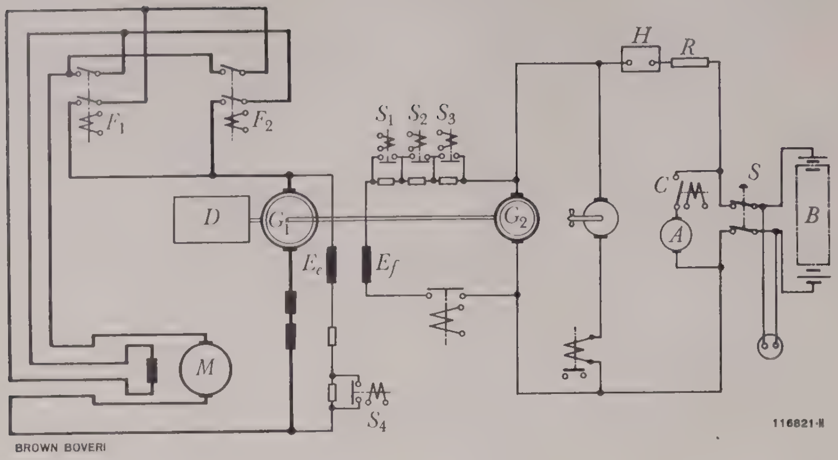

Fig. 1. – Circuit diagram of a transmission system employing the dual-characteristic principle

For explanation of the notation see text.

the temperature rise of the field winding the governing factor is the maximum speed or the maximum voltage at corresponding excitation current. Although the two values, high voltage and high current, do not occur simultaneously, the size of the generator must be determined by the product of the one-hour current and the maximum voltage—representing the power for which it is dimensioned—for reasons associated with the temperature rise.

Particularly with high outputs it is important for the power for which the generator is dimensioned to be kept within acceptable limits, so that no difficulties are experienced when assembling the machines in the locomotive, resulting from their being too large and too heavy. In such cases it is, therefore customary to reduce the dimensioned output of the generator by field weakening or series-parallel connection of the traction motors, or by some special circuit arrangement. The field of the traction motors may be weakened in steps or continuously and automatically

Choice of Electrical Transmission System

The various transmission systems from which a choice may be made are as follows:

- Direct Ward-Leonard system with separately excited generator. With this system the excitation is adapted to the desired tractive effort, steps being taken to avoid inadmissible reduction of the speed of the diesel engine. This system is too complicated and uneconomical.
- The Gebus system is preferable. Here a self-excited generator is employed, so that the voltage drops at heavy currents. This method can be used for low powers but has the drawback of lower current when short-circuited than on-load, which is not conducive to good starting.
- In Germany the system known as RZM control used to be popular, with which voltage and current relays prevent the desired output being exceeded, by reducing the excitation.
- For high outputs the combination of separate and self-excitation of the generator and the provision of a counter-compound winding has become more or less generally accepted. The latter winding is used, where possible, for starting the diesel engine. This is not always possible, so that a special starting winding is sometimes needed, especially when a high generator voltage is chosen.
- The dual-characteristic method allows full advantage to be taken of the output of the diesel engine over a wider working range. One characteristic is designed for a high starting tractive effort, the other for high running speed. Employing this method Brown Boveri have supplied, or have on order, over 200 generators for a dimensioned output of about 500 kW at a speed of 1500 rev/min.

Fig. 1 shows the circuit diagram of a diesel-electric system employing the dual-characteristic principle. The diesel engine D is coupled with the main generator G_1 and the auxiliary generator G_2. With the aid of the switch S the starter motor A is connected across the battery B through contactor

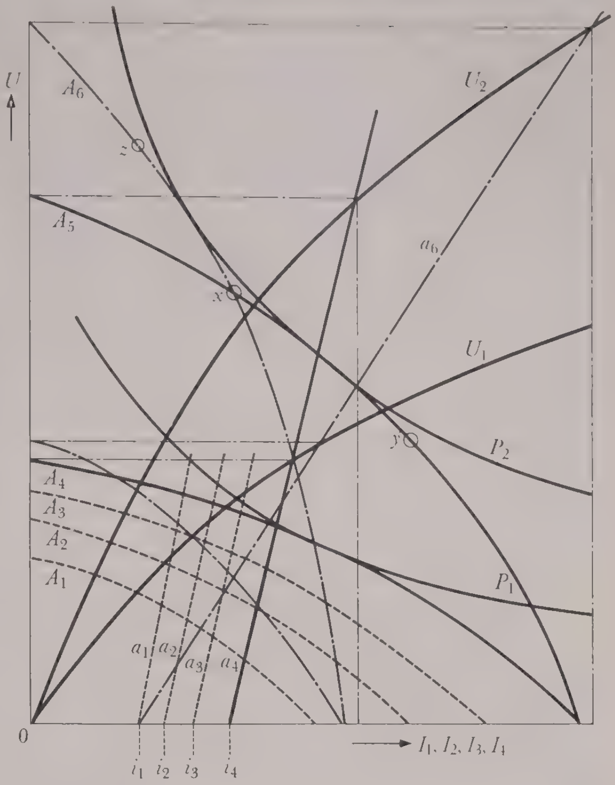

Fig. 2. – Operating curves appertaining to the circuit shown in Fig. 1 (dual-characteristic method)

U_1, U_2 = Voltage curve of the generator for the speeds n_1, n_2 of the diesel engine
P_1, P_2 = Outputs of the diesel engine at the speeds n_1, n_2
a_1, a_2, a_3, a_4 = Resistance lines corresponding to the excitation currents i_1, i_2, i_3, i_4
A_1, A_2, A_3, A_4 = Characteristics of the diesel-generator for the output P_1 of the diesel engine at the respective resistance lines a_1, a_2, a_3, a_4
A_5 = Characteristic of the generator for an output P_2 of the diesel engine at the resistance line a_4
A_6 = Characteristic of the generator for an output P_2 of the diesel engine at the resistance line a_6

C, i.e. for the diesel engine in this example a special machine is employed for starting the diesel. The traction motor *M* is connected to the main generator by the changeover contactors F_1 and F_2. The voltage of the auxiliary generator G_2 is kept constant by the voltage regulator *H*. The auxiliary generator charges the battery through the resistor *R*. As soon as its voltage is high enough, the auxiliary generator is connected to the battery by a contactor. If the voltage becomes too low, causing a reverse current to flow, the auxiliary generator is disconnected from the battery.

In order to set different values of the separate excitation, and thus obtain different starting currents, resistance steps are incorporated in the separate excitation winding E_f, which are cut in by the contactors S_1, S_2 and S_3. A high voltage at the generator is obtained by varying the self-excitation E_s by means of the contactor S_4.

Fig. 2 illustrates the conditions obtained with this circuit arrangement. For example, with the separate excitation currents i_1, i_2, i_3 and i_4 we obtain the corresponding characteristics A_1, A_2, A_3 and A_4. With the latter characteristic it is possible to attain the highest starting current, or in other words the maximum tractive effort. This characteristic is therefore suitable for starting under severe conditions. The characteristic A_4 must not intersect the power hyperbola P_1 corresponding to the speed n_1, otherwise the speed and output of the diesel engine will drop considerably. To drive the vehicle at a higher speed, the speed of the diesel can be raised to n_2. Thus the voltage *U* is raised from the characteristic A_4 to A_5. If a still higher speed is desired, it is possible to switch over from A_5 to A_6 at about the point *x*. The characteristic A_6 corresponds to maximum speed but minimum starting current; that is to say, if the trailing load is light, the locomotive can start up on the characteristic A_6 direct. From Fig. 2 it can also be seen that, with the assistance of the dual-characteristic method, full advantage is taken

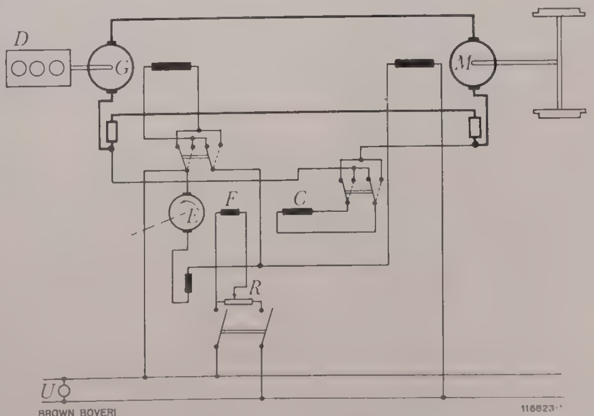

Fig. 3. – Circuit diagram for automatic field weakening of a traction motor

For notation see text.

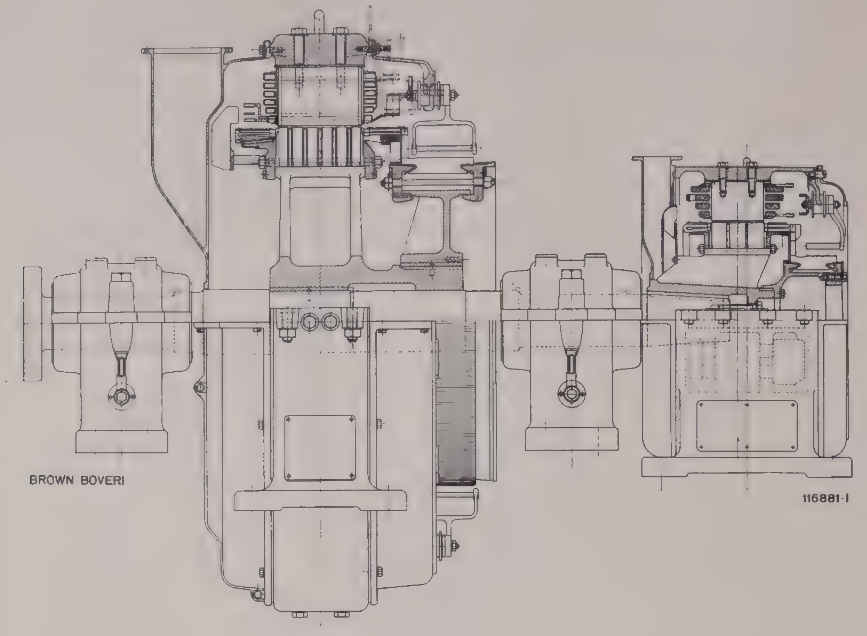

Fig. 4. – Section through a diesel-generator set built in 1928, for an output of 1225 kW at 450 rev/min

This set weighed 14 t, corresponding to a power/weight ratio of 0·09 kW/kg.

of the output of the diesel engine over quite a wide range, for instance from *x* to *y*.

For higher outputs the Brown Boveri system of servo-field control is best. It allows full benefit to be gained from the output of the diesel engine and corrects any difference in the temperature rise of the electrical machine and loss of output from the diesel in the event of a cylinder failing, for example. With very high diesel outputs it is important for the dimensioned output of the generator not to be too high, because this might result in difficulties regarding the weight, size and commutation of the generator. A smaller dimensioned output can be attained by designing the traction motors

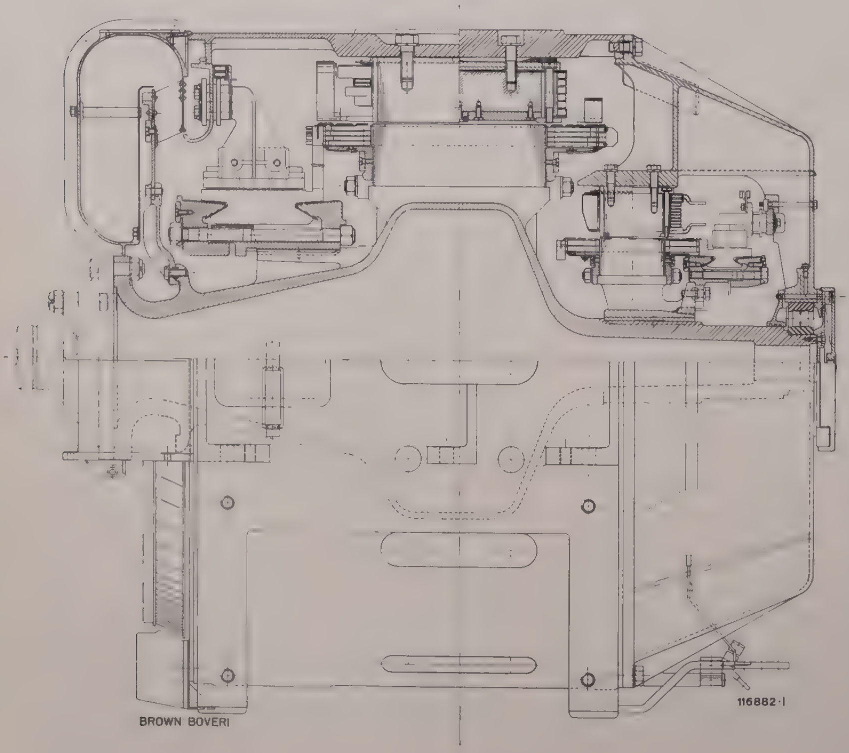

Fig. 5. – Section through a modern diesel-generator set built in 1959 for an output of 2100 kW at 900 rev/min

In contrast to the set in Fig. 4, this one only weighs 7·9 t yet produces 1·7 times as much power, giving a power/weight ratio of 0·26 kW/kg. The long design with large diameter and pedestal bearings has given way to a compact design with trunnion bearings and built-in auxiliary exciter. Depending on the space available and the layout of the locomotive, the auxiliary generator can be mounted partly under the rotor winding or at the commutator of the latter. For high auxiliary generator outputs belt drives are avoided where possible.

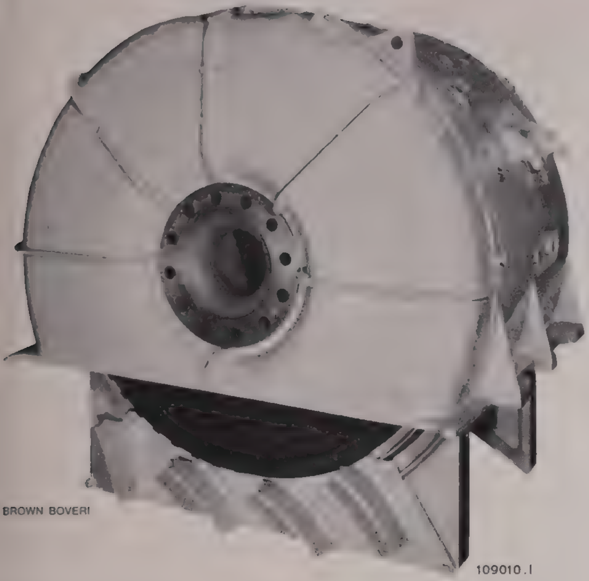

Fig. 6. – Generator set as shown in Fig. 6, ready for coupling to a diesel engine rated 2100 hp

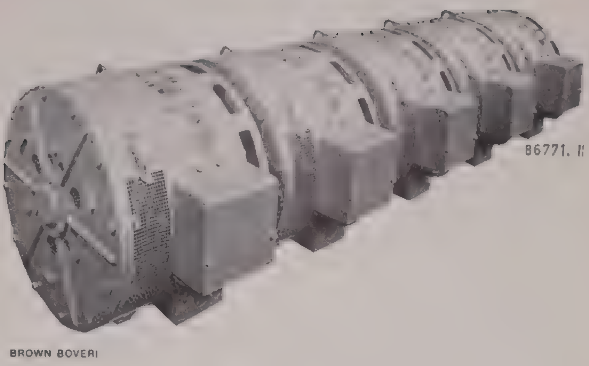

Fig. 8. – Small generators with body and shaft for direct flange-mounting on the diesel engine

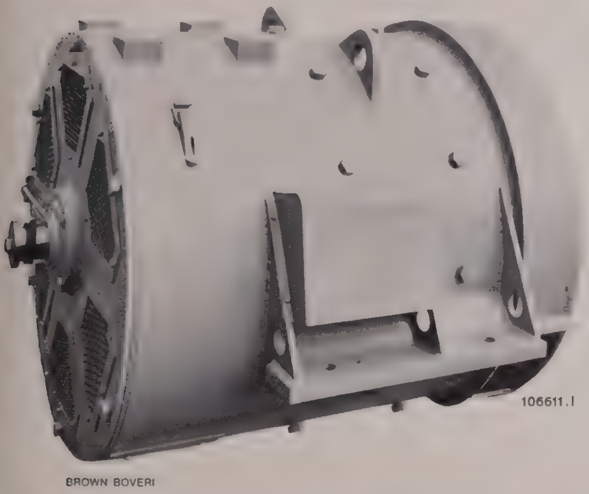

Fig. 7. – Diesel-generator for shunting engines

Dimensioned output 500 kW at 1500 rev/min. Driven by a diesel engine rated 300–600 hp.

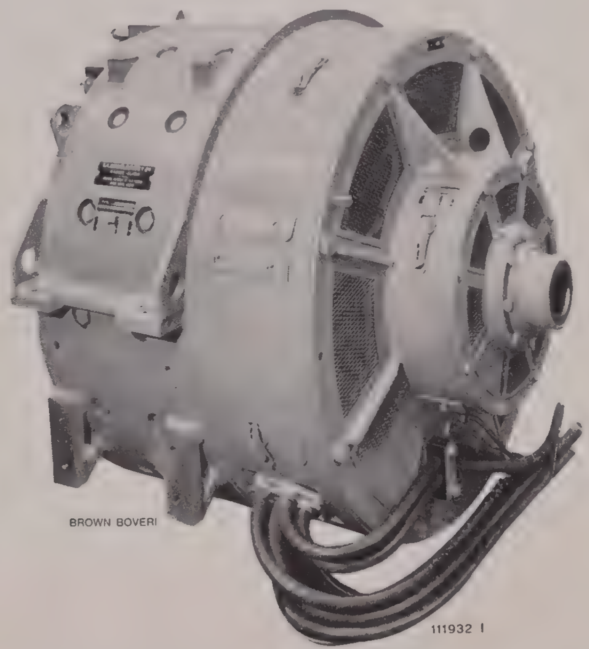

Fig. 9 – Diesel-generator set in which the auxiliary generator is mounted below the commutator of the main generator

Rated 670 kW at 870 rev/min.

for severe field weakening, e.g. in several steps. If this system is adopted, a corresponding number of steps must be available.

Fig. 3 shows a circuit for automatic field weakening of the traction motor. The diesel engine *D* drives the generator *G* feeding the traction motor *M*. The auxiliary exciter *E* is excited by the winding *F* of a constant-voltage source *U*, and by the winding *C*, which is influenced by the main current of the motor *M*. If the voltage at the auxiliary exciter and thereby the excitation of the generator is increased, the motor field is simultaneously weakened. This results in smooth, continuous regulation. The servo-field control system can act on the resistor *R* or on the field of the main generator. This automatic system of field weakening is employed by Brown Boveri for drives of fishing-net hoists, machine tools, cranes and the like.

Progress made in the evolution of diesel-generator sets in roughly the last thirty years is illustrated in Fig. 4–9.

(KME) H. WEIER

TRACTION VEHICLES FOR LOCAL SERVICES

621.335.4:625.6

This article deals with some of the electrical equipments which have been supplied recently for motor-coaches employed for local transport services, e.g. underground railways, tram and trolleybus lines. In the course of developing such vehicles, the main stress was laid on articulated units, as they are, without doubt, going to be the principal vehicles used by local services in the future.

Motor-Coaches of the Series 400 and 600 of the Barcelona Underground Railway

IN 1953 the Company supplied the electrical equipment for eleven motor-coaches of the 300 series. The good results obtained led to the order being placed for 36 sets for new motor-coaches intended for duty on the "Transversal" and "Sagrera–Horta" lines. The switchgear and control system for the traction motors, the motor-generators and their controls, and the regulating equipment for the battery charging circuits were all supplied from Baden. The traction motors for 14 units of the 600 series were built in Spain, while the motors for a further 6 units of the 400 series (Fig. 1) will be made to Brown Boveri drawings by Maquinista Terrestre y Marítima in Barcelona.

The existing network of the Barcelona Underground is shown in the sketch map in Fig. 2, the lines on which vehicles equipped with Brown Boveri equipment are serving being marked specially. The electrical equipment for the motor-coaches of the new series are designed on the same lines as those of the older 300 series [1].[1] Although the service voltages of the two lines are different (1500 V d.c. on the Transversal line, and 1200 V d.c. on the Sagrera–Horta line), it is nevertheless possible to employ the same control gear.

Cam-Operated Switchgear

The cam-operated mechanism (Fig. 3) is driven by a servo-motor and contains switchgear elements with individual blowout. It comprises:

- the actual master controller which shorts out the starting and braking resistors and controls the grouping of the traction motors;
- the drive, consisting of the electric motor and intermittent grooved cam;

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[1] The figures in square brackets refer to the bibliography at the end of the article.

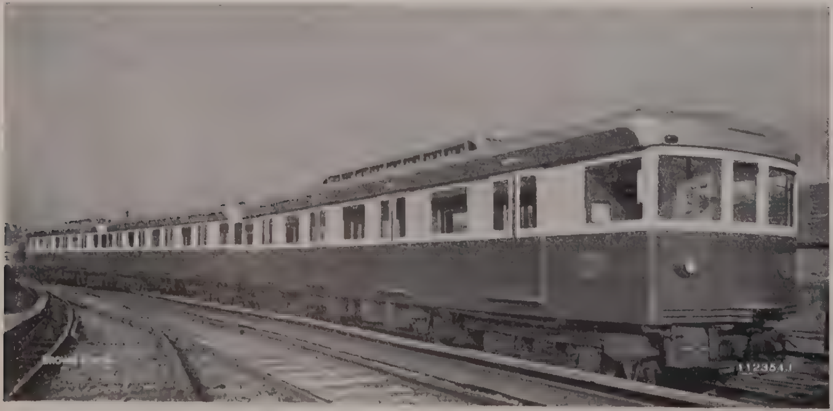


Fig. 1. – Barcelona Underground composition of the 400 series, comprising two motor-coaches and one trailer

Total output of the eight traction motors 768 kW at 33·4 km/h. Capacity 350 passengers.

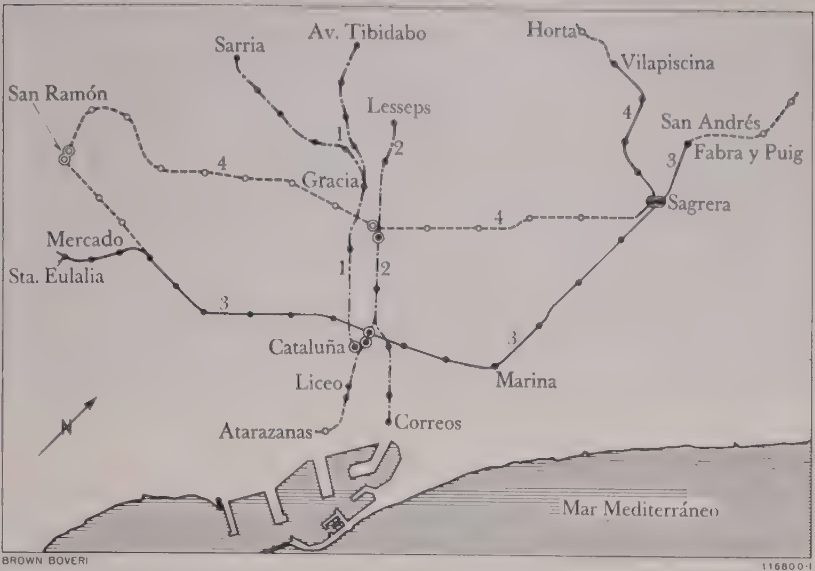


Fig. 2. – The network of the Barcelona Underground

——— = Routes covered by vehicles equipped by Brown Boveri

–·–·– = Routes covered by vehicles equipped by other firms

– – – – = Projected routes

- the drum with the auxiliary contacts;
- the frame with the control contactors and associated resistors.

All parts are mounted on a rigid framework, attached to the vehicle at three points.

With the switchgear the following connections and groupings can be effected in the traction motor circuit:

- changing over the motors from pairs in series to parallel by means of a bridge connection;
- shorting out the starting resistors in 13 steps with series grouping and in 6 steps for parallel grouping, notching up being effected automatically under the supervision of a current relay;
- shorting out the starting resistors used as braking resistor in 13 steps, in this case notching up being automatically supervised by a braking-current relay and an overcurrent relay. On the first braking notch the motor fields are also separately excited from the overhead wire.

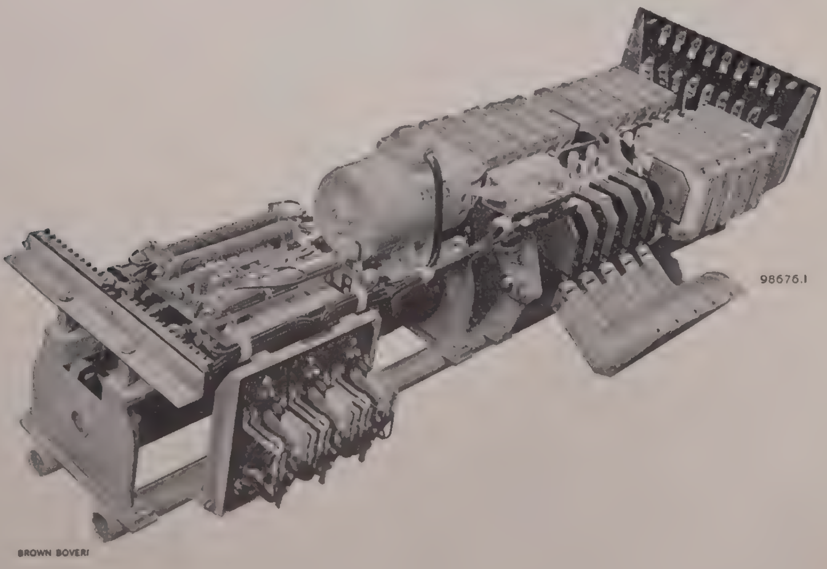


Fig. 3. – Cam-operated switchgear operated by an electric servo-motor and employed on the motor-coaches series 400 and 600 of the Barcelona Underground

13 series notches, 6 parallel notches and 13 braking notches. All elements are equipped with individual blow-out.

Rated voltage 1500 V

Rated current per element 160 A

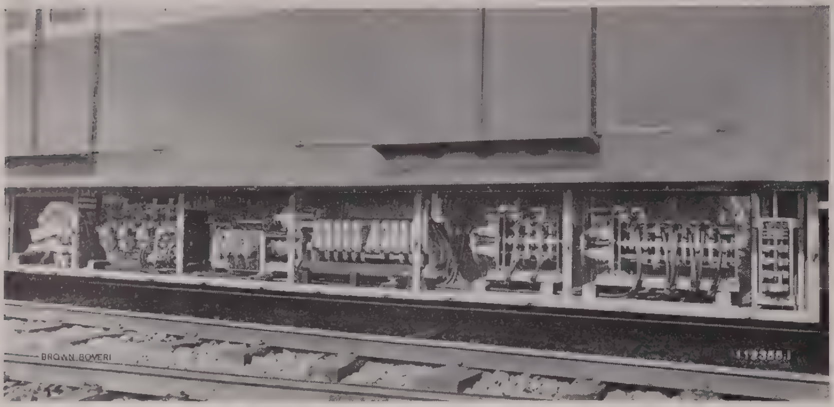


Fig. 4. – Assembly of the switchgear for the traction motors of the series 400 and 600 motor-coaches

From left to right: electro-pneumatic line contactor, motoring and braking-current relays, overvoltage relay, cam-operated switchgear, reversing switch, brake changeover switch, disconnecting switch for motor groups.

In order to commence braking without loss of time, the cam-operated controller is always returned to zero by the shortest route when the master controller is set to "Braking". When the changeover switch has prepared the braking circuit for action, the cam-operated controller begins to short out the resistors.

The assembly of the switchgear for the traction motors is illustrated in Fig. 4. The circuit diagram of the traction motor circuits for motoring and braking can be seen in Fig. 5.

Master Controller

As mentioned above, the control of these vehicles is semi-automatic and supervised by relays for the motoring and braking current. This simplifies the task of the driver and, at the same time enhances the reliability. Apart from the zero position the controller has three motoring positions (shunting, motors in series and in parallel) and two braking positions.

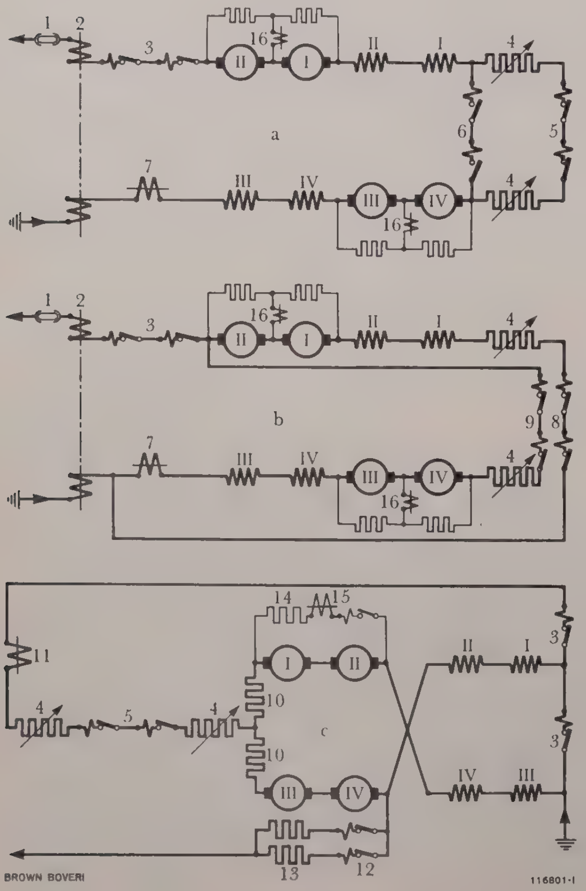


Fig. 5. – Circuit diagram for motoring and braking of the series 400 and 600 motor-coaches of the Barcelona Underground

a: Motoring in series
b: Motoring in parallel
c: Braking
I–IV = Traction motors
1 = H.R.C. fuse
2 = Differential relay
3 = Electro-pneumatic line contactor
4 = Starting and braking resistors
5 = Grouping switch (series)
6 = Bridge switch
7 = Acceleration relay (motoring current)
8, 9 = Grouping switches (parallel)
10 = Supplementary braking resistors
11 = Retarding relay (braking current)
12 = Contactor for separate excitation when braking
13 = Series resistor
14 = Resistor in series with 15
15 = Overvoltage relay
16 = Anti-slip relay

Traction Motors for the Series 400 Motor-Coaches

The motors are designed for the following performance:

Terminal voltage	1350/2 V
One-hour rating	96 kW at 1140 rev/min and 156 A
Continuous rating	77 kW at 1260 rev/min and 125 A

They are amply dimensioned, so that the rheostatic brakes can be employed as the service brake.

Articulated Trams for the Municipal Services in Basle and Zurich

In 1959 the Municipal Transport Services of Basle (BVB) and Zurich (VBZ) ordered the electrical equipment for two and one articulated trams respectively. The coachwork and bogies were supplied by the Swiss Industry Co. (SIG) in Neuhausen. These vehicles will commence service during the winter 1960/61. Although the two tramway networks operate under different conditions, an attempt was nevertheless made to standardize to a certain extent on certain components, such as the traction motors, parts of the motor control gear, motor-generator set, heating, ventilating and lighting equipment.

The characteristic data of these two types of vehicle are as follows:

	BVB	VBZ
Vehicle type	Be 4/6	Be 6/6
Total one-hour rating of the traction motors	264 kW	396 kW
Corresponding tractive effort	3400 kg	5200 kg
Corresponding speed	27·1 km/h	26·6 km/h
Max. permissible speed	60 km/h	60 km/h

The dimensions of the vehicle are shown in Fig. 6, which illustrates the four-motor tram of the BVB.

Traction Motors and Transmission

Each bogie has two motors, mounted lengthwise on rubber shock-absorbing elements. To ensure that the vehicle runs as quietly as possible, a number of measures were taken. The torque is transmitted from the motor to the axles by a Cardan shaft and worm gearing, and the wheels contain rubber elements. Moreover, the earthing brushes normally in contact with the wheel flange were replaced by brushes making end-on contact with the axles and enclosed.

The different topographical conditions encountered in the Basle and Zurich networks account for the different ratings of the motors. Basle has no long, steep sections like Zurich. In both places a trailer must be hauled. Under these circumstances the BVB motor-coaches are equipped with four motors, that of the VBZ with six. The characteristic curves of the two sets of equipment are plotted in Fig. 7 and 8.

Connection and Switchgear for Traction Motors

On account of the different numbers of traction motors, two different circuit arrangements had to be devised. For the four-motor vehicles the conventional arrangement was adopted, with pairs of motors, each motor taking half the voltage, the pair being permanently in series. For starting, the four motors are all in series, subsequently being changed over to pairs in parallel by means of a bridge connection. For braking, these two pairs run with crossed fields on the starting resistor acting as braking resistor.

With the six-motor tram a simpler arrangement was adopted by dispensing with regrouping of the motors. There are thus three separate pairs of motors, each pair having its own switchgear and starting resistor. On the first notch, the three pairs are switched on successively until the tractive effort approaches the adhesion limit, when the starting resistors are simultaneously shorted for all three groups. When braking, each pair runs on its own

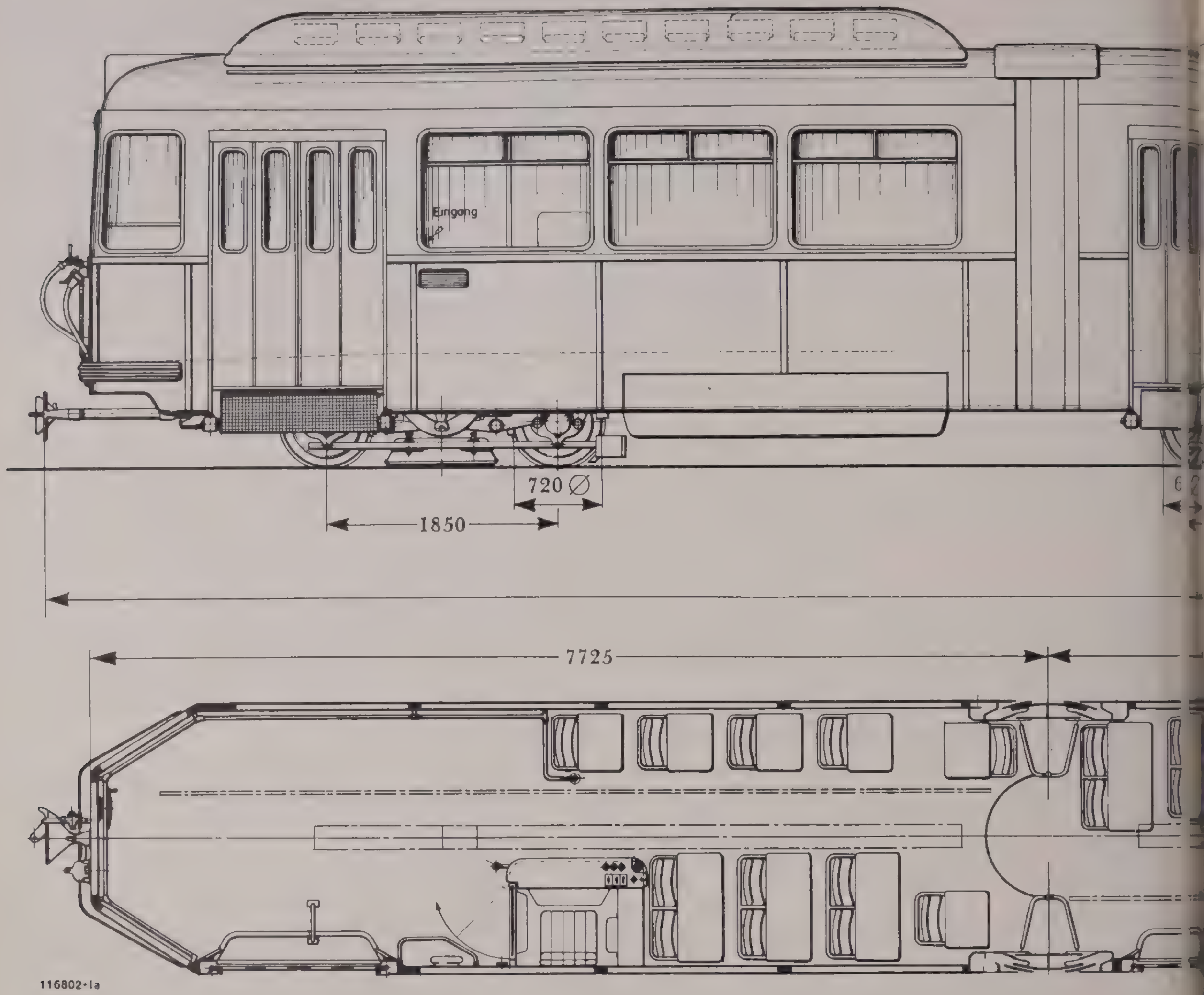


Fig. 6. – Articulated tram, built by the Swiss Industry Co., Neuhausen, for the Basle Municipal Transport Dept.

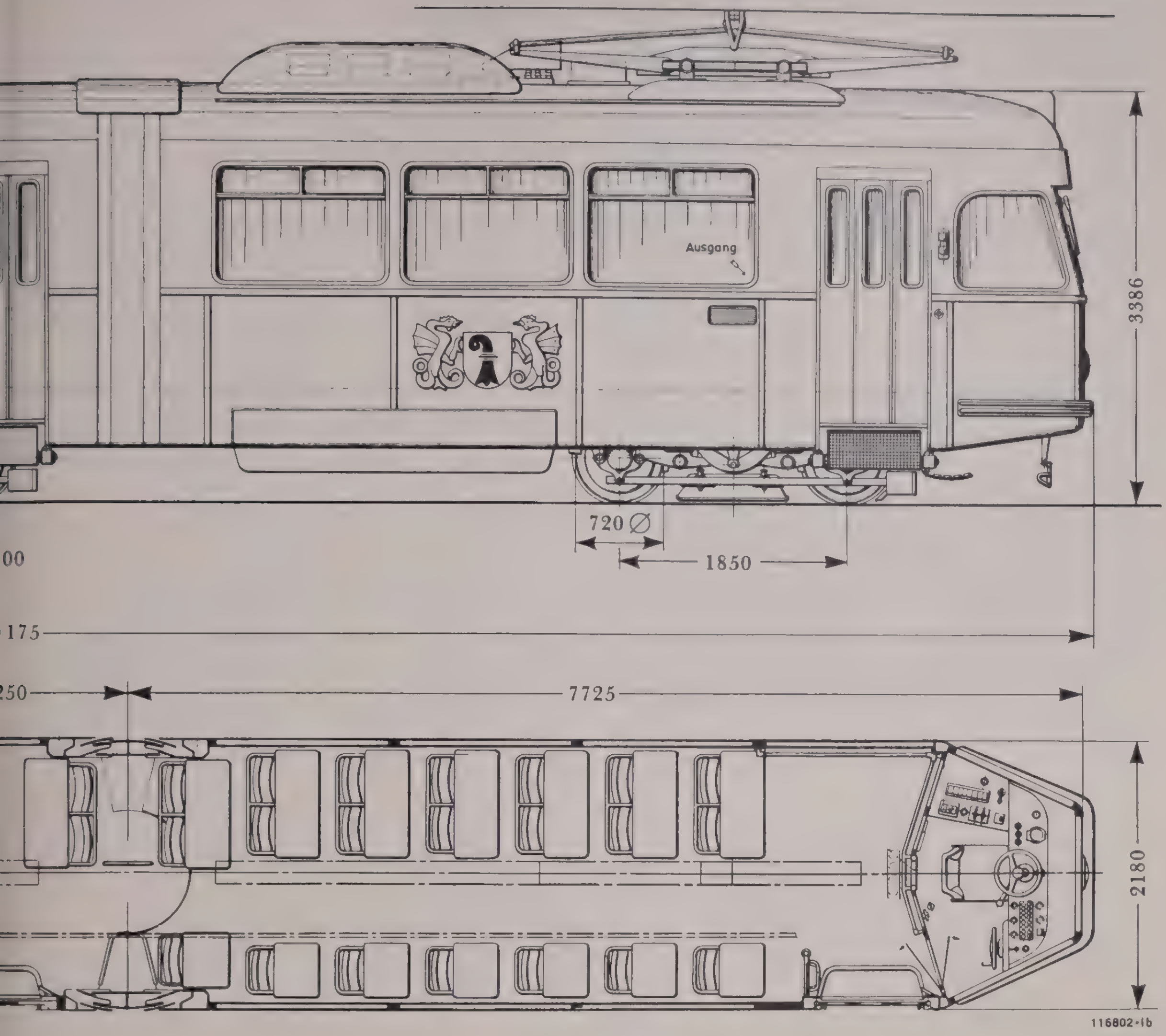
This vehicle is powered by four traction motors mounted lengthwise and developing a one-hour output of 264 kW at 27·1 km/h. Capacity 43 seated passengers, 122 standing. Dimensions in mm.

starting resistor in a separate braking circuit, thereby greatly improving the reliability of the braking system.

Every effort was made to use as many switchgear elements of the same kind as possible. Also the number of cables for the motor circuits, which have to pass through the junction, had to be kept as small as possible. This requirement rendered the use of a common brake changeover switch and a common reversing switch impossible. Consequently a switchgear layout was chosen in which the grouping of the motors, switching over and all control actions are performed by contactors of the same type. With a suitable arrangement of the switchgear it is, for example, possible to employ certain contactors for the braking circuit and for reversing.

The electro-magnetic contactors are very slim in order to make best use of the available space. They are of the same design as has been employed for years with conspicuous success in trolleybuses.

The selected arrangement of the switchgear provides the following number of notches:



a. For BVB trams:

22 starting notches, of which

15 are for series grouping and

7 are for parallel grouping. Also

3 field-weakening notches for speed control without loss,

13 notches for rheostatic braking and

1 notch for the electro-magnetic rail brake.

b. For the VBZ tram:

22 starting notches,

3 field-weakening notches for speed control without loss,

22 notches for rheostatic braking and

1 notch for the electro-magnetic rail brake.

The switchgear is manipulated by the master controller, with which the control switches for reversing and disconnecting the motors are combined.

The Be 4/6 trams of the BVB are equipped with starting and braking resistors of conventional design.

For the Be 6/6 tram of the VBZ the resistance volume is considerably larger, owing to the different connection and the fact that there are 6 motors instead of 4. A compact, light resistor was obtained by employing the vane-type resistance elements described in the article on page 566.

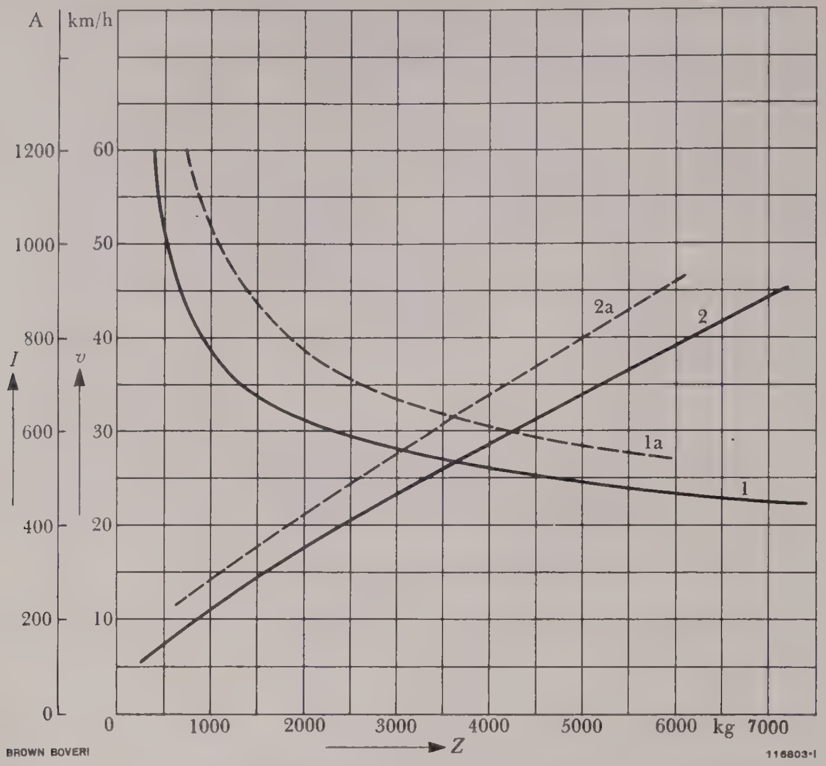


Fig. 7. – Characteristics of the four-motor tram type Be 4/6 of the BVB (Basle)

Total one-hour output	264 kW
Supply voltage	600 V d.c.
Wheel dia. (half worn)	690 mm
Gear ratio 1:6·375	

Z = Tractive effort in kg
v = Speed in km/h
I = Motor current in A
1 = Speed at full field
1a = Speed with weakened field
2 = Total motor current at full field
2a = Total motor current with weakened field

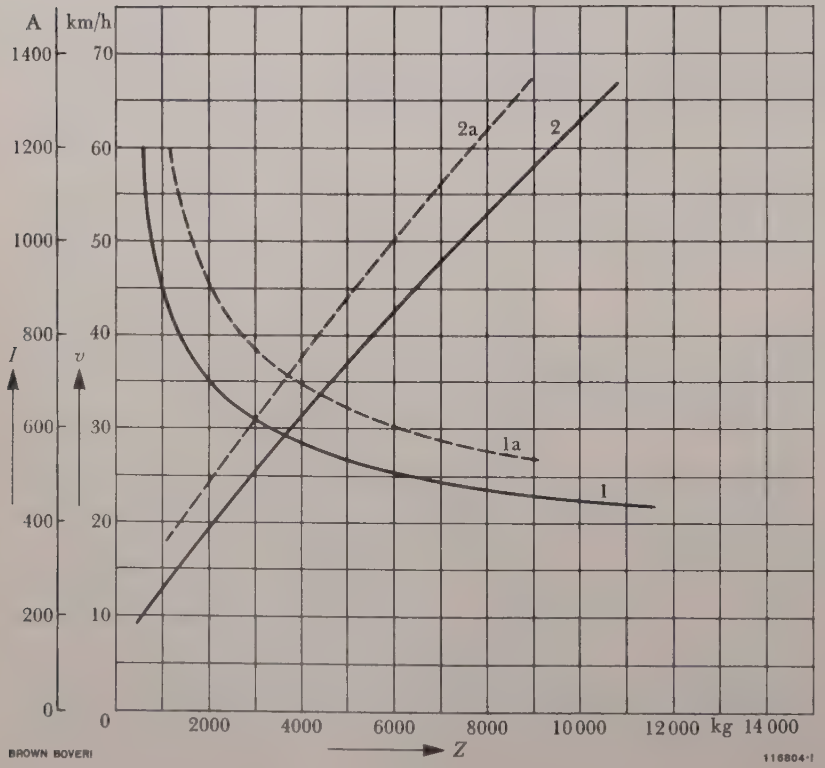


Fig. 8. – Characteristics of the six-motor tram type Be 6/6 of the VBZ (Zurich)

Total one-hour output	396 kW
Supply voltage	600 V d.c.
Wheel dia. (half worn)	680 mm
Gear ratio 1:6·375	

Notation as in Fig. 7

Trams Without Pneumatic Equipment

The Municipal Transport Department of the City of Milan (ATM), having taken delivery of a large number of trams with electrical equipment of conventional design, supplied by Tecnomasio Italiano Brown Boveri (TIBB), called for two trams with all-electric equipment, i.e. without any pneumatic gear at all [2]. The problems encountered were cleverly solved, to the customer's complete satisfaction, so that now there are 18 articulated trams of this kind under construction (Fig. 9).

Bogies, Traction Motors and Brakes

The standard design of bogie being built by TIBB, with motors mounted lengthwise, transmission comprising Cardan shaft and bevel gearing, and rubber-sprung wheels, was retained. The electric and mechanical brakes are matched to obtain the best effect; the vehicles possessing the following braking equipment:

- The electric rheostatic brake, with which the motors act as generators on the starting resistor.
- The electro-mechanical brake, acting direct on the axles.
- The electro-magnetic rail brake.

The normal service brake consists of a combination of the first two brakes and is applied by a single braking controller.

By means of a special braking circuit, in which the fields of the motors are separately excited by the generator of the converter set, the braking force only changes slightly within a wide speed range, as shown by Fig. 10. Since the excitation current of the motors decreases with increasing speed, it has to be interrupted as soon as it exceeds a certain level, when the brakes are applied. The vehicle is then brought to a standstill with the electro-mechanical brake alone (see the braking circuit in Fig. 11).

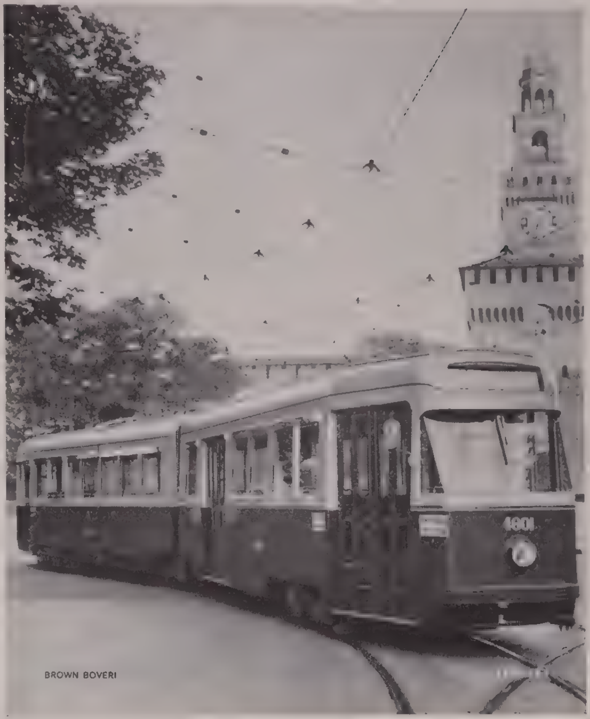


Fig. 9. – Articulated tram of the Milan City Tramways with a one-hour rating for four traction motors totalling 220 kW at 29·2 km/h

Providing room for 36 seated and 139 standing passengers.

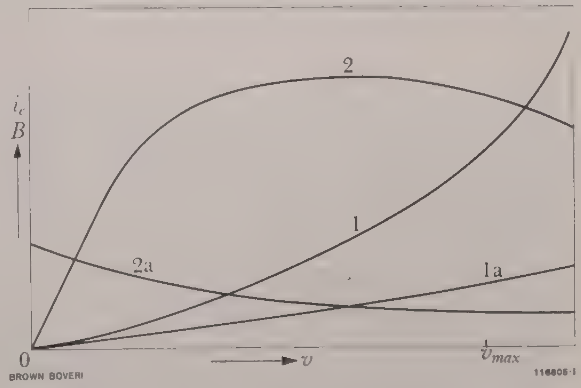


Fig. 10. – Curve of braking force and excitation current in terms of the speed v

1 = Braking force with series-excited motors
1 a = Excitation current with series-excited motors
2 = Braking force with self-compensated braking circuit and separately excited motors
2 a = Excitation current with self-compensated braking circuit and separately excited motors
B = Braking force
i_e = Excitation current

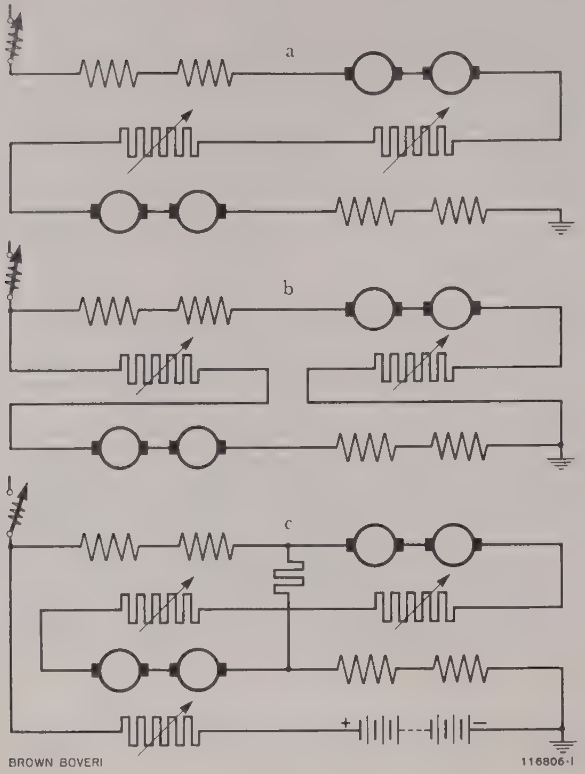


Fig. 11. – Schematic circuit diagrams for motoring and braking of the all-electric trams of the Milan City Tramways

a: Motors in pairs in series
b: Motors in pairs in parallel
c: Braking

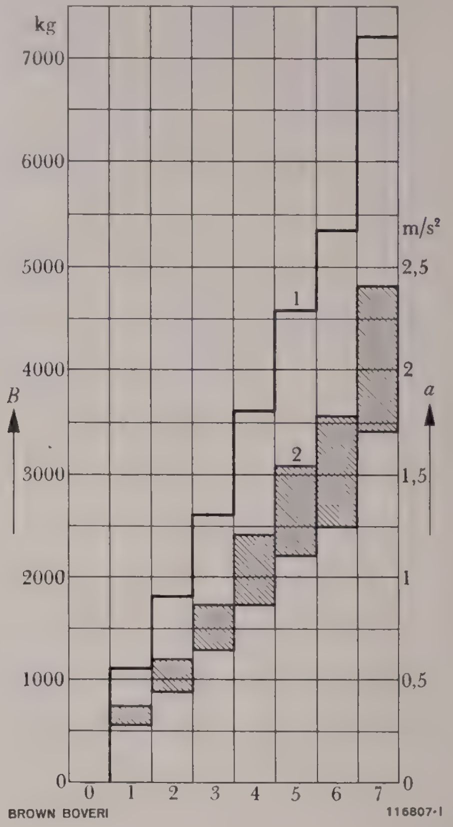


Fig. 12. – Braking force on notches 1–7 and attainable deceleration with loaded and empty tram. Recorded for the all-electric trams of the Milan City Tramways

B = Braking force in kg
a = Deceleration in m/s²
1 = Braking force 2 = Deceleration

The electro-mechanical brake fulfils all conditions with regard to reliability. In the event of an interruption on the line, the brake shoes close automatically under the action of the springs. Since the braking discs are mounted direct on the axles and not on the Cardan shaft, for instance, the braking force is transmitted directly by drive elements, which are not overloaded in consequence. The brake blocks also act on a disc rotating relatively slowly, which is also advantageous. The electro-mechanical brake is ideal for holding the vehicle at a standstill.

The trams can be braked in a total of seven steps. The distribution of the braking force and the attainable retardation when the tram is loaded and unloaded are depicted in Fig. 12. On notch 7 the rail brake comes into action in addition to the rheostatic and electro-mechanical brakes, so that deceleration up to about 2 m/s² are possible, depending on the load and the state of the rails.

Switchgear for the Traction Motors and Their Control

This comprises twelve electro-magnetic contactors, which are used as notching, motoring, and braking contactors, with strip starting and braking resistors, a main switch, reversing switch, motor switch and the equipment for automatic starting, which prevents the master controller giving the notching contactors a command to advance as long as the current exceeds a certain level. The notching rate is set by means of a pendulum. The master controller has the following positions:

"0" All circuits disconnected.

"M" First motoring position, on which both pairs of motors are in series and all resistance in circuit, the automatic system not having come into action.

"S" The automatic system comes into action and controls the stepwise shorting of the starting resistors in eight steps, until the four traction motors are simply in series and the first economical motoring stage has been attained.

"P_B" Switching the motors over to pairs in parallel and shorting out the resistors, controlled by the automatic system in seven stages. The tractive effort is set to that for the empty vehicle.

"P_N" The same functions as on P_B, except that the tractive effort is set for the vehicle when half full.

"P_A" As for P_B, except that the tractive effort is set for the fully loaded vehicle.

Articulated Compositions for the Centovalli Railway (Locarno–Domodossola)

The rolling stock taken into service in 1923, for which the electrical equipment was supplied by TIBB, Milan, had for a long time been unable to cope with the demands of tourist traffic on this line, which is the shortest connection between the Gotthard and Simplon routes, i.e. between Ticino and Lake Geneva. The line is operated jointly by the Swiss company Ferrovie Regionale Ticinesi (FRT) and the Italian undertaking Società Subalpina di Imprese Ferroviarie, and covers a distance of 52 km with a number of long, severe uphill and downhill sections. For lines with similar conditions, such as the Rome–Fiuggi route, the electrical equipment for the rolling stock was supplied by TIBB, and has given excellent results [3, 4]. These are eight-motor vehicles which take full advantage of the adhesion and, in Italy, are looked upon as the normal type of vehicle for such routes. It was consequently an obvious solution to employ the same kind of unit in the present case (see Fig. 13). The contract to supply four articulated motor-coach sets was entrusted to Brown Boveri and the Schindler Carriage and Wagon Works, Pratteln [5].

Bogies and Motors

The bogies built by TIBB, which have not only been used for trams on many occasions, but also for several cross-country railway routes, are equipped

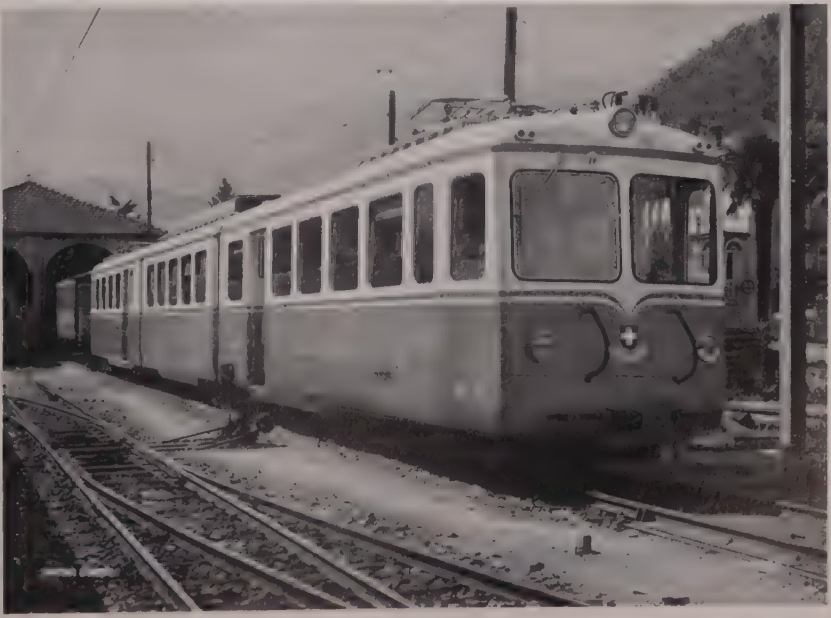


Fig. 13. – Articulated motor-coach unit of the Centovalli Railway (Locarno-Domodossola) with a one-hour output of 720 kW at 43·5 km/h

(Photo by courtesy of Schindler Wagon Co., Pratteln)

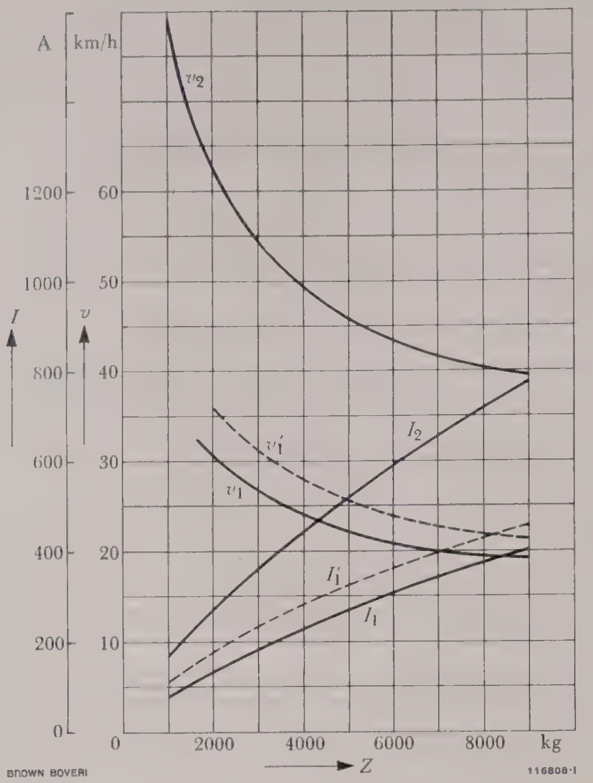


Fig. 14. – Characteristics of the eight-motor articulated motor-coach sets of the Centovalli Railway type ABe 8/8

One-hour output	720 kW
Supply voltage	1300 V d.c.
Wheel diameter	780 mm

Z = Tractive effort in kg

v_1, v'_1 = Speed in km/h with series-connected motors, at full and weakened field, respectively

v_2 = Speed in km/h with parallel-connected motors, at full field

I_1, I_1' = Current input in A with series-connected motors, at full and weakened field, respectively

I_2 = Current input with parallel-connected motors, at full field

with a pair of self-ventilated traction motors suspended lengthwise, having the following data:

Terminal voltage	1300/2 V d.c.
One-hour rating	90 kW at 1350 rev/min and 152 A
Continuous rating	65 kW at 1500 rev/min and 110 A

The characteristics of the eight-motor equipment are shown in Fig. 14.

Switchgear

The switchgear for the eight traction motors consists of electromagnetic contactors. These receive their operating impulses from a master controller and form the automatic starting gear. The switching rate is controlled by a pendulum. The automatic gear also prevents the controller from giving a command to advance when the current exceeds a certain value. Provision is also made for preselecting two different pick-up values for the overcurrent relay, according to the magnitude of the desired tractive effort. It can, however, be advanced notch by notch, without the automatic gear coming into action.

Fig. 15 shows the traction motor circuits, from which it can be seen that the motors are always grouped in pairs and that there are four pairs altogether. The connection for starting is evident from this diagram. The changeover from series to parallel connection is effected by the bridge connection.

The circuit for electric braking is basically the same as in the trams described in the previous chapter and is also illustrated in Fig. 15.

Should the motor-generator set fail, the capacity of the battery is sufficiently large to maintain the excitation of the motors during one downhill run.

Auxiliaries

The circuits for control, lighting and excitation of the traction motors during braking are fed from a monobloc motor-generator connected with a battery, charging of which is supervised by a rolling-sector regulator. The pneumatic elements are supplied from a Brown Boveri motor-compressor unit.

Articulated Trolleybuses

The traffic on routes served by trolleybuses has also greatly increased, especially at the peak periods. Changing tram routes over to trolleybuses, and introducing additional routes has also caused the number of trolleybuses to grow. To illustrate this point the figures for Italy may be quoted [6]:

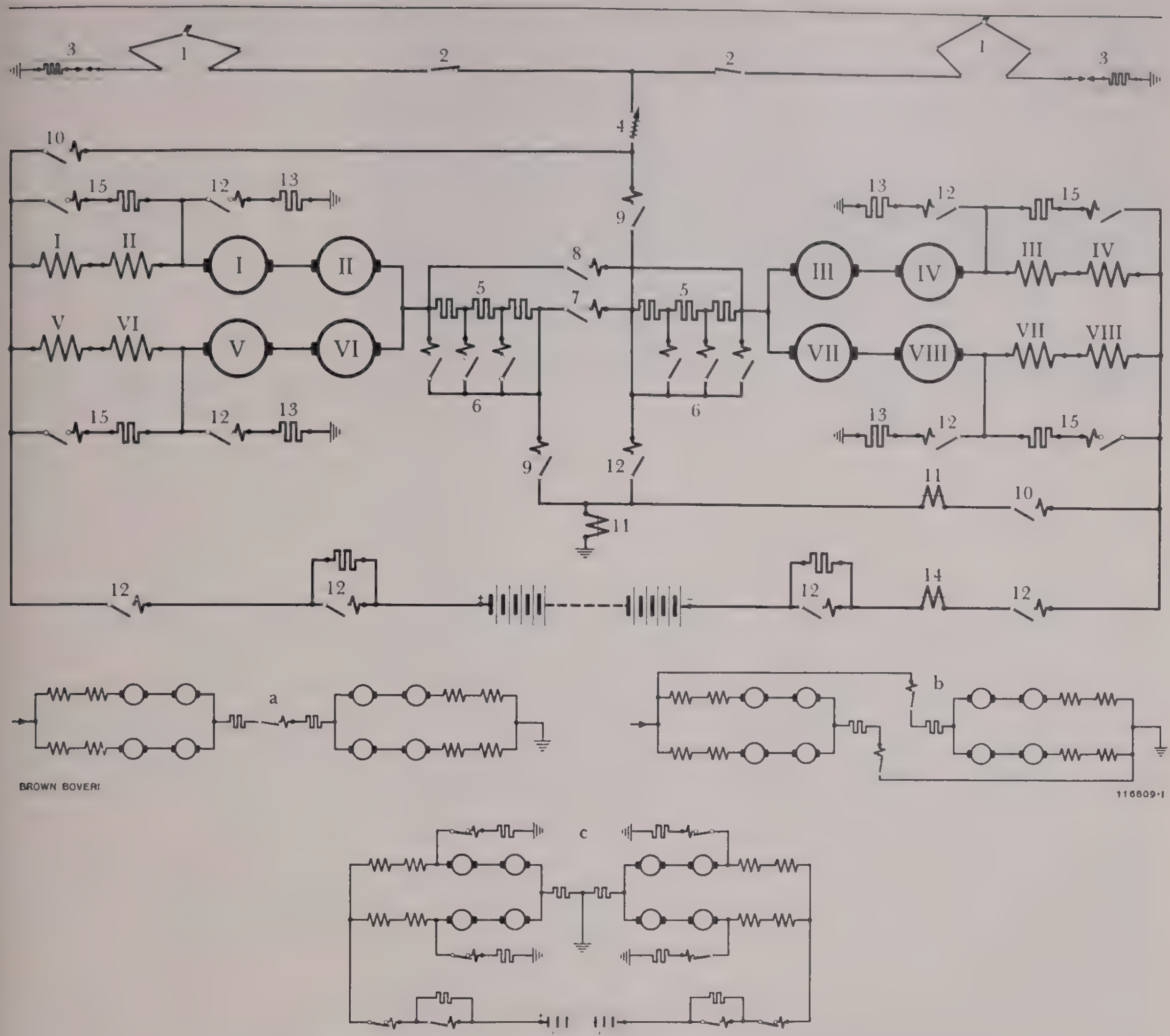


Fig. 15. – Motor-coach sets type ABe 8/8; schematic circuit diagram of the traction motor circuits

a: Motors all in series b: Motors connected series-parallel c: Braking

I–VIII = Traction motors
1 = Current collector
2 = Isolating switch
3 = Lightning arrester
4 = Main breaker with overcurrent relay
5 = Starting and braking resistors
6 = Notching contactors
7 = Grouping contactor (series)
8 = Bridge contactor
9 = Grouping contactors (parallel)
10 = Motoring contactor
11 = Acceleration relay
12 = Braking contactors
13 = Braking resistors
14 = De-excitation relay
15 = Field-weakening system

	Route distance km	Number of trolley-buses	Distance covered by vehicles 10^6 km	Passengers (millions)
1947	427	642	28·1	485
1956	1061	1927	100·2	1064
Ratio 1947: 1956	2·5	3	3·6	2·2

The demand for more transport capacity on an existing line is being satisfied nowadays by the introduction of articulated trolleybuses. A major contribution to the rapid evolution of trolleybus services in Italy was made by TIBB, Milan, who have supplied a large number of articulated vehicles recently. These are equipped for contact-wire voltages of 600 or 1200 V d.c., in some cases for

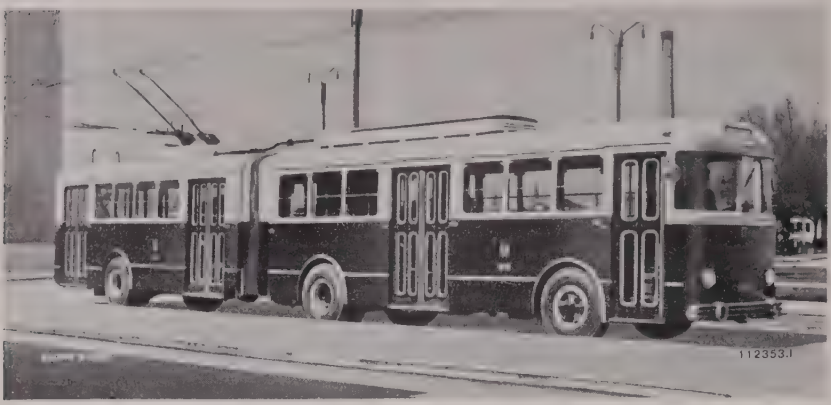


Fig. 16. – Articulated trolleybus in Verona (Italy)

One-hour output 2 × 100 kW at 37 km/h

Supply voltage 1350 V d.c.

Capacity 142 passengers

both. The motors employed are of the single- or double-commutator design, each vehicle being fitted with one or two such motors; in the latter case the motors are connected either in series or in parallel.

Switching operations in the motor circuits are performed by electromagnetic contactors, controlled in terms of the current by an automatic system. Fig. 16 shows an articulated trolleybus serving Verona in Italy. The Table below lists the data of a number of similar trolleybuses for which TIBB have supplied the electrical equipment [7, 8].

Electrical Equipment for Trolleybuses of the Winterthur Municipal Transport Dept.

The switchgear system put forward some years ago by Brown Boveri for trolleybuses [9], in which all elements of the h.v. circuits are combined in a block insulated from the body of the vehicle, was also employed in the eight newest units supplied to the Winterthur Municipal Transport Dept. (Fig. 17). Similar sets are in service in Basle, Zurich, St. Gall, Biel (all in Switzerland), in Bergen (Norway) and in Linz and Leoben (Austria) [10].

Transport company	Number of articulated trolleybuses	Weight empty/full t	Passengers	Supply V d.c.	Number of motors, connection	One-hour rating kW	Acceleration at start m/s²	Top speed km/h	Control	Notches
Consorzio Filovie Torino-Rivoli	15	16·7 26	144	600 1200	1	194	0·95	60	electro-magnetic contactors, automatic	14
Filovie Provinciali Verona	21	15,5 25	142	1350	2 series	2 × 100	1·05	70	,,	12
Azienda Tranvie Municipali, Torino	15	16 26	144	600	1	180	1·0	44	,,	12
Azienda Tranviaria Municipale, Milano	5	14 24	141	600	2 parallel	2 × 125	1·0	60	,,	14
ESHOT, Smyrna (Turkey)	3	16	144	600	1	180	1·0	44	,,	12

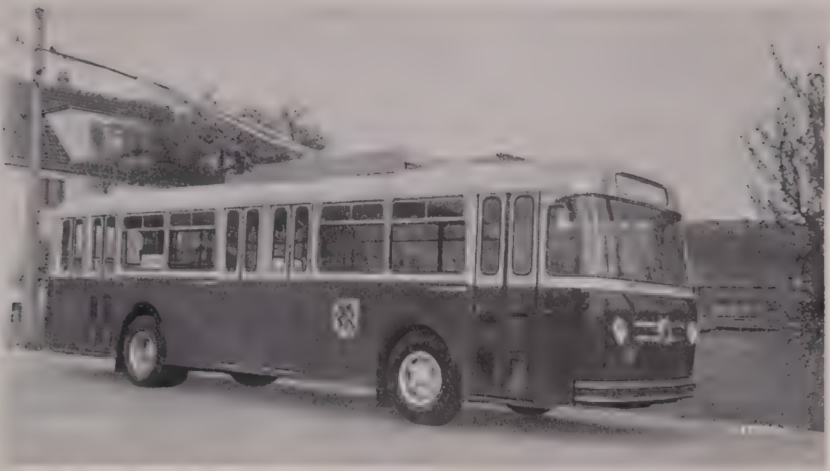


Fig. 17. – Trolleybus in Winterthur (Switzerland)

One-hour output
100 kW at 23·5 km/h

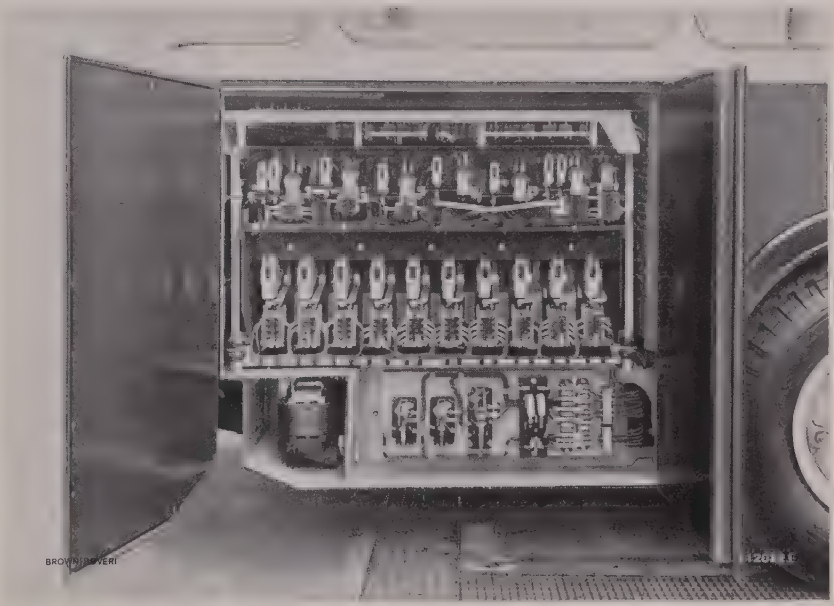


Fig. 18. – Switchgear block mounted in the side panel of the above trolleybus

The upper block contains the contactors for the traction motor circuits, the lower block those for the compressor and motor-generator.

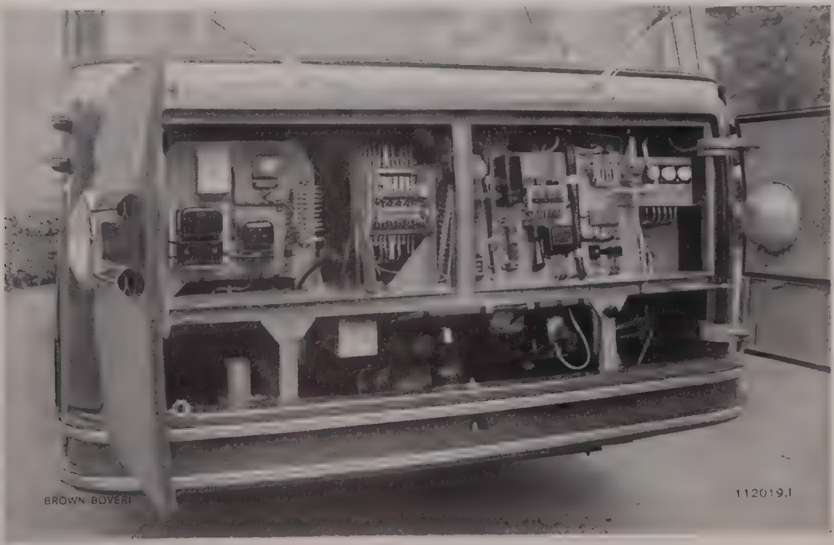


Fig. 19. – Switchgear compartment in the nose of the above trolleybus

containing the low-voltage switchgear. Note the smallness of the master controller.

Fig. 18 shows a typical block mounted in the side of the trolleybus, containing the control gear for the traction motor. The neat arrangement allows all elements of the h.v. gear to be inspected with ease. In the main circuit the well-tried electromagnetic contactors rated 150 A at 600 V are employed as reversing, notching and braking contactors. As will be seen, this circuit dispenses with a reversing switch and brake changeover switch in the main circuit. The functions of these switches are entrusted to a combination of contactors. The field-weakening contactors for the traction motor as well as the contactors for certain auxiliaries, are electromagnetically operated. Mounted at the rear of the block are the field-weakening resistors for the motor and the resistors reducing the current carried by the electromagnetic contactors. Mounted behind the front panel in compartments, separated from the high-voltage gear, is the whole of the low-voltage equipment (Fig. 19).

All switching operations in the traction motor circuit can be controlled by the master controller. This is designed for seven motoring notches with full field, six of which are with resistors, three with field-weakening and seven braking notches. The reversing switch for the control system is combined with the master controller.

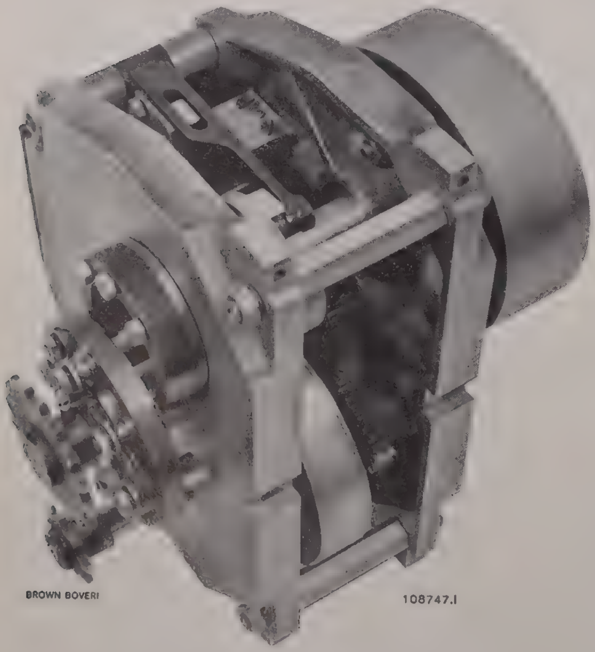


Fig. 20. – Timing mechanism for automatic starting and braking

Employed in trolleybuses in conjunction with the master controller in Fig. 19.

It is also possible for starting and braking to be carried out automatically by trolleybuses fitted with this equipment, provided there is a timing mechanism between the pedals and the master controller.

The starting and braking resistors are accommodated in an enclosure below the floor of the bus. They are ventilated by a forced draught, the hot air being conveyed through a system of ducting in winter to heat the interior of the vehicle, emerging through heaters beneath the seats.

The traction motor is the d.c. series motor with double commutator, which has been successfully employed in a number of other installations. Its main data are as follows:

Rated voltage	600 V
One-hour rating	100 kW at 1350 rev/min, 185 A
Continuous rating	76 kW at 1450 rev/min, 140 A

With a gear ratio of 1 : 10·52 and a wheel diameter of 98 cm, the one-hour output provides a tractive effort of 1500 kg at a corresponding speed of 23·5 km/h. At the maximum permissible service speed of the traction motor the top speed of the bus is 50 km/h.

The bodywork of these buses was made by Adolph Saurer & Co. Arbon. Each vehicle can carry 22 sitting and 60 standing passengers, and has a tare weight of 9·1 t.

Automatic Equipment for Notching-up and Braking on Trolleybuses

Owing to the increasing density and hazards of traffic in the cities nowadays, the driver of a trolleybus is subjected to increased demands as regards his concentration. To relieve him of the responsibility for uniform notching-up, a number of foreign trolleybuses—recently in Switzerland too—have been equipped with automatic systems controlling starting and braking.

An example is the timing mechanism developed by Brown Boveri (illustrated opposite in Fig. 20), which was fitted a number of years ago in 18 trolleybuses for Bergen in Norway. This unit, which has rendered excellent service, is 27 cm high, 18 cm wide and 22 cm deep.

Aided by this timing mechanism, the driver can put his foot hard down on the accelerator or brake pedal, to the end notch, the notching-up action of the master controller is then automatically supervised by the timing mechanism. The rate of switching is governed by a rotating mass. If the starting or braking current exceeds the prescribed figure, the controller is prevented from continuing. This block is cancelled as soon as the current has dropped to the permitted value. This mechanism functions dependably, regardless of the position in which it is mounted, and the position of the vehicle.

(KME) W. ZBINDEN

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NEW MULTIPLE-UNIT STOCK FOR THE SPANISH STATE RAILWAYS (RENFE)

621.335.42(46)

A group of Swiss firms which specialize in the construction of traction vehicles, received an order for 15 three-coach combinations to be used on the newly-constructed Spanish 3000-V d.c. railway system. Brown Boveri received the order for the supply of the bulk of the electrical equipment. In this article the author describes the new traction vehicles with particular attention to the equipment supplied by Brown Boveri.

IN 1946 a programme for the reconstruction and electrification of their main routes was drawn up by the Spanish State Railways (Red Nacional de los Ferrocarriles Españoles—RENFE). In order to be able to cope with the ever increasing traffic RENFE decided to order 143 multiple-unit combination of various types.

The Multiple-Unit Stock Supplied from Switzerland

The order placed with a group of Swiss firms[1] covered 15 three-coach combinations of the type WMD-WR-WM consisting of a motor-coach with luggage compartment, a trailer coach and another motor-coach with passenger compartment. Spanish firms are to build the remaining vehicles under licence from this Swiss syndicate.

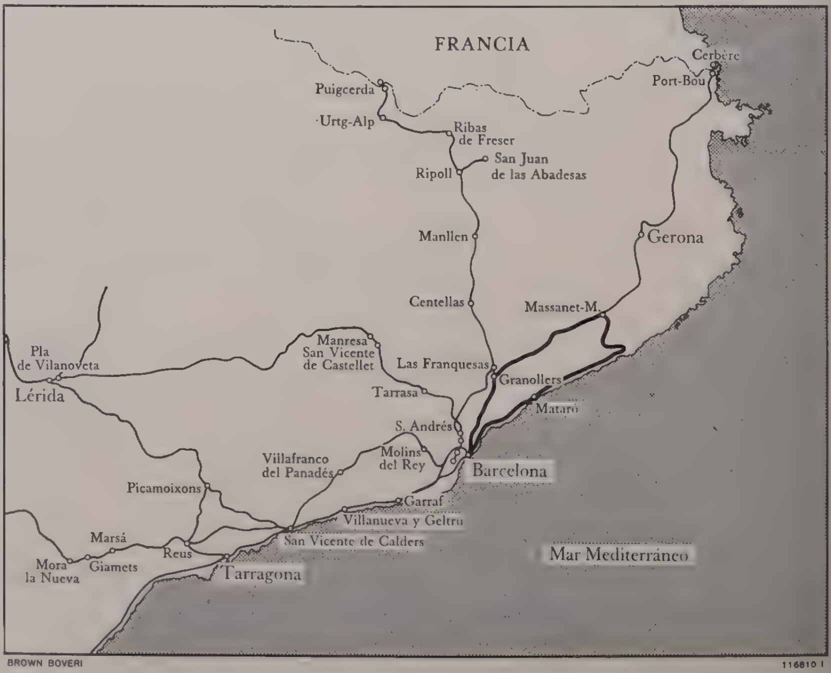

Fig. 1. – Map of Catalonia

The heavy lines show the sections on which the new multiple combinations are to operate.

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[1] Swiss Car and Elevator Corp., Schlieren-Zürich
Schindler Waggon AG, Pratteln
S.A. des Ateliers de Sécheron, Geneva
Brown, Boveri & Co., Ltd., Baden

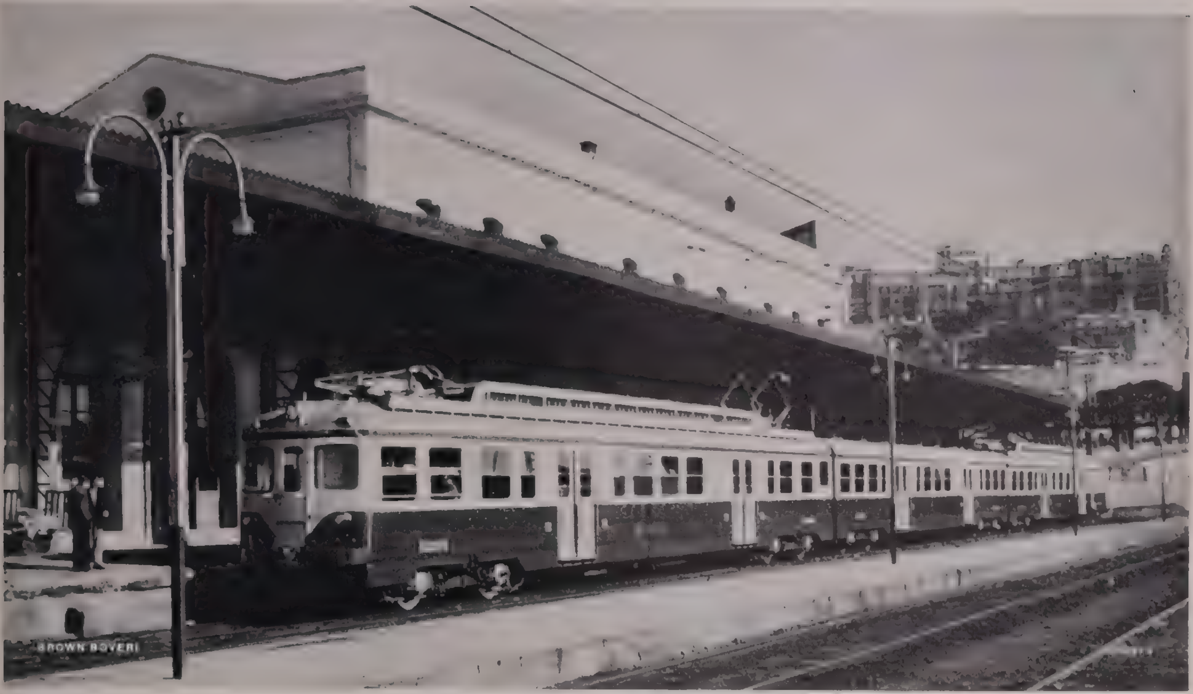


Fig. 2. – One of the first ten combinations at Tarragona station during the trial and acceptance runs

The one-hour rating of the combination at 61 km/h is 2060 kW (2800 hp); maximum speed 110 km/h.

The 15 trains went into normal service between August 1958 and April 1960. The "Catalonian figure-of-eight" (Fig. 1), as the suburban network of Barcelona is locally named, is an ideal field of operation for these new units. Firstly, the lines have to serve a number of industrial towns while secondly, the seaside resorts impose very heavy traffic. The multiple-unit trains of the WMD-WR-WM type (Fig. 2 and 3) have 28 second-class seats, 232 third-class seats (in Spain the third class is still common) as well as standing accommodation for 376 persons. The total capacity is thus 636 persons. The tare weight of such a combination is 146 t. The two motor-coaches, each with 2 bogies fitted with 2 traction motors each, have two driver's cabs—one at each end—one of which is a main and the other a secondary control stand. All vehicles are provided with Scharfenberg couplings for the mechanical, electrical and pneumatic connections between the coaches.

The suburban traffic imposes exacting demands for the rolling stock and requires particularly high peak loading reserves. On top of that the traction vehicles have to be capable of a high acceleration because of the short distances between stations and the close timetable.

The two motor-coaches of each combination are identical as far as the electrical equipment is concerned. Each has a one-hour rating of about 1000 kW. The whole combination can be accelerated with 0·8 m/s² to a speed of 55 km/h (Fig. 4, starting diagram). With a combination of only one motor-coach plus one trailer, type WMD-WR, an average acceleration of 0·6 m/s² up to 60 km/h can still be achieved. Fig. 5 shows the tractive effort–speed curves of a combination type WMD-WR-WM at a voltage of 3000 V d.c. with half-worn tyres. Further, the diagram shows the resistance to forward motion for a fully loaded railway combination of 211·4 tons on the flat and on inclines of 1·65, 3 and 4 ‰.

Electrical Equipment

Fig. 6 shows the schematic diagram of the traction motor circuits for a motor-coach. Each motor-coach

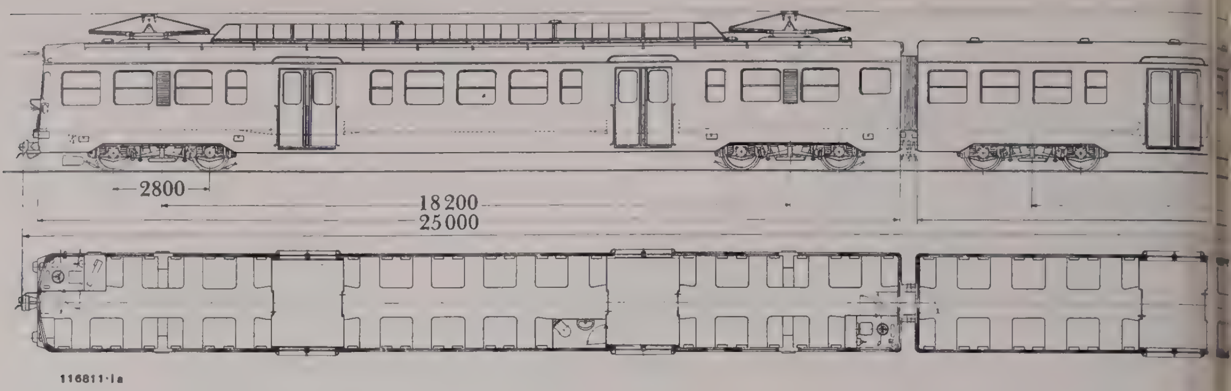


Fig. 3. – Elevation, plan, leading dimensions and short specification of a three-coach combination (WMD-WR-WM)

Dimensions in millimetres

Further dimensions:	
Gauge	1·674 m
Wheel diameter (new)	1·006 m
Maximum height (pantographs retracted)	4·2 m

	Luggage motor-coach (WMD)	Trailer coach (WR)	Motor-coach (WM)
Tare weights	57·8 t	30·7 t	57·8 t

is equipped with four traction motors, which are connected permanently as pairs in series, thus permitting the pairs to be connected in series and parallel. The changeover can be effected without decrease in the tractive effort by a bridge connection. The traction motors can have their fields weakened by 25 and 40% in the series as well as parallel-connected motor groups, resulting in a total of six possible motoring stages. For starting, 18 steps are available with full field, comprising 12 steps in series connection and 6 in series-parallel connection. This process can be automatically controlled either by current-sensitive acceleration relays or it can be controlled manually. (The master con-

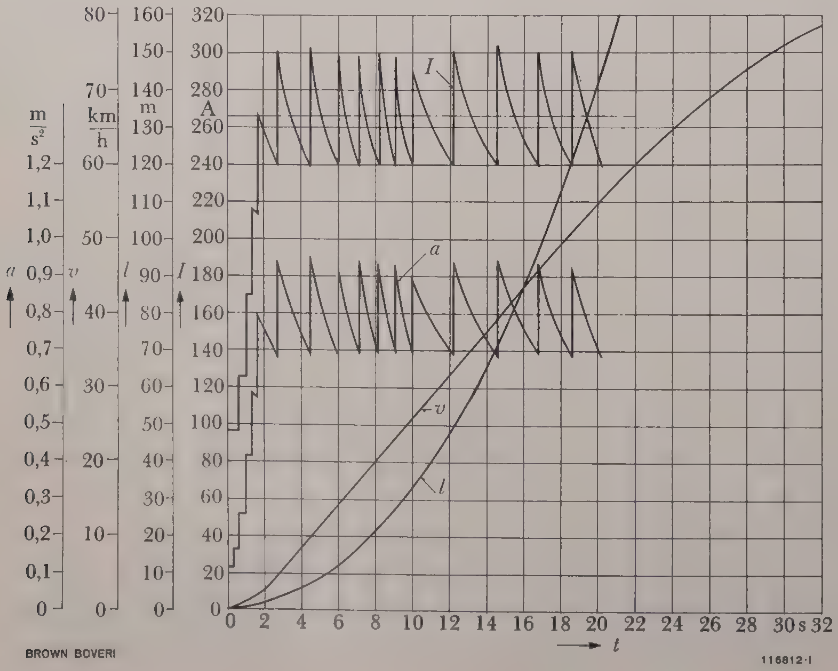
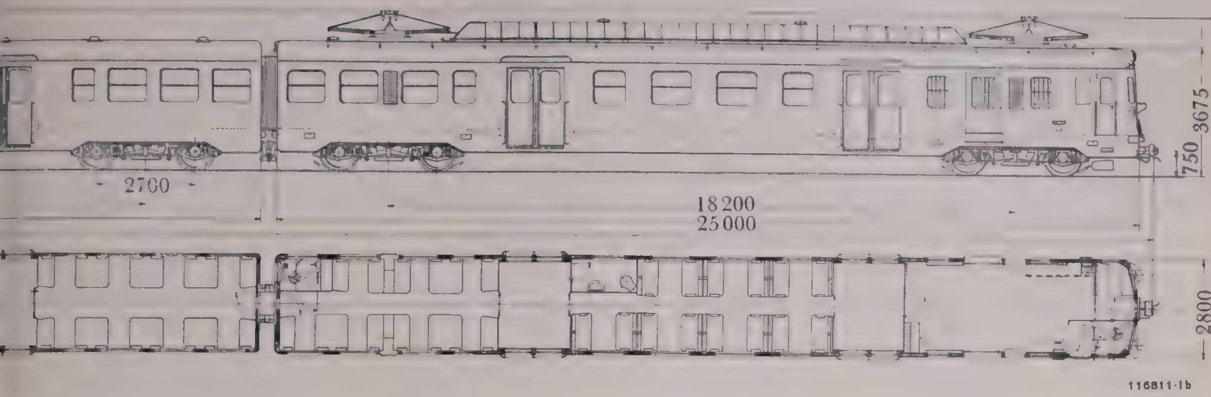


Fig. 4. – Starting diagram of a combination, consisting of motor-coach with luggage compartment, trailer coach and motor-coach, all loaded, on level track

I = Starting current per motor in A
a = Acceleration in m/s²
v = Speed in km/h
l = Distance in m
t = Time in s



Total weight of combination		146·3 t	
Loading capacity	22·7 t	21·5 t	20·9 t
Total gross weight	—	211·4 t	—
Seats 2nd class	—	—	28
Seats 3rd class	92	100	28
Emergency seats	12	—	—
Standing room	120	120	136
Total accommodation of combination (WMD-WR-WM)		636	

Electrical data

Rated voltage	3000 V
Minimum voltage	2100 V
Maximum voltage	3660 V
One-hour rating at motor shaft at 3000 V	2060 kW (2800 hp)
Tractive effort at wheel rim	12200 kg
Corresponding speed	61 km/h
Average starting tractive effort	19500 kg
Maximum speed	110 km/h

troller in the secondary control stand has no provision for automatic starting and acceleration. Depending on the type of combination, the acceleration relay is set to a higher or lower rate of acceleration. The starting resistances are cut out by electro-pneumatic contactors.

The motor-coaches are also equipped for regenerative braking in 13 steps, the power being dissipated in resistors. This system can be applied between 110 and 20 km/h and permits the train to run at a steady downhill speed of between 70 and 20 km/h on inclines of 2%.

Arrangement of the Electrical Equipment

A great deal of attention was paid to the arrangement of the electrical gear, which leaves as much room as possible for passenger accommodation. This resulted in most of the electrical apparatus being installed in compartments under the floor. Starting and braking resistors, isolating switches and lightning arresters are mounted on the roof of the motor-coaches. Only the relays, the circuit-breaker and the fuses are arranged in separate cubicles in the rear wall of the driver's cab.

Traction Motors

The four-pole self-ventilated traction motors are equipped with double commutators, and are mounted on the bogies (Fig. 7). Their output data at a terminal voltage of 3000/2 V and full excitation are as follows:

		continuous	one-hour rating
Output at the shaft	kW	221	258
Current	A	158	187
Speed	rev/min	1140	1070
Corresponding speed	km/h	65	61

The torque is transmitted to the axles by means of a lamellar drive with Cardan shaft and a gearbox with a ratio of 67:21 = 3·19. Fig. 8 shows a rotor with its hollow shaft, the two commutators and the fan. The air inlet openings are arranged on the sides of the motor casings and are provided for the connection of the air ducts. These air ducts have their inlets high up on the sides of the motor-coaches in order to keep the cooling air as free from dust as possible.

Operational experience has shown that these rugged motors have an extremely high overload capacity.

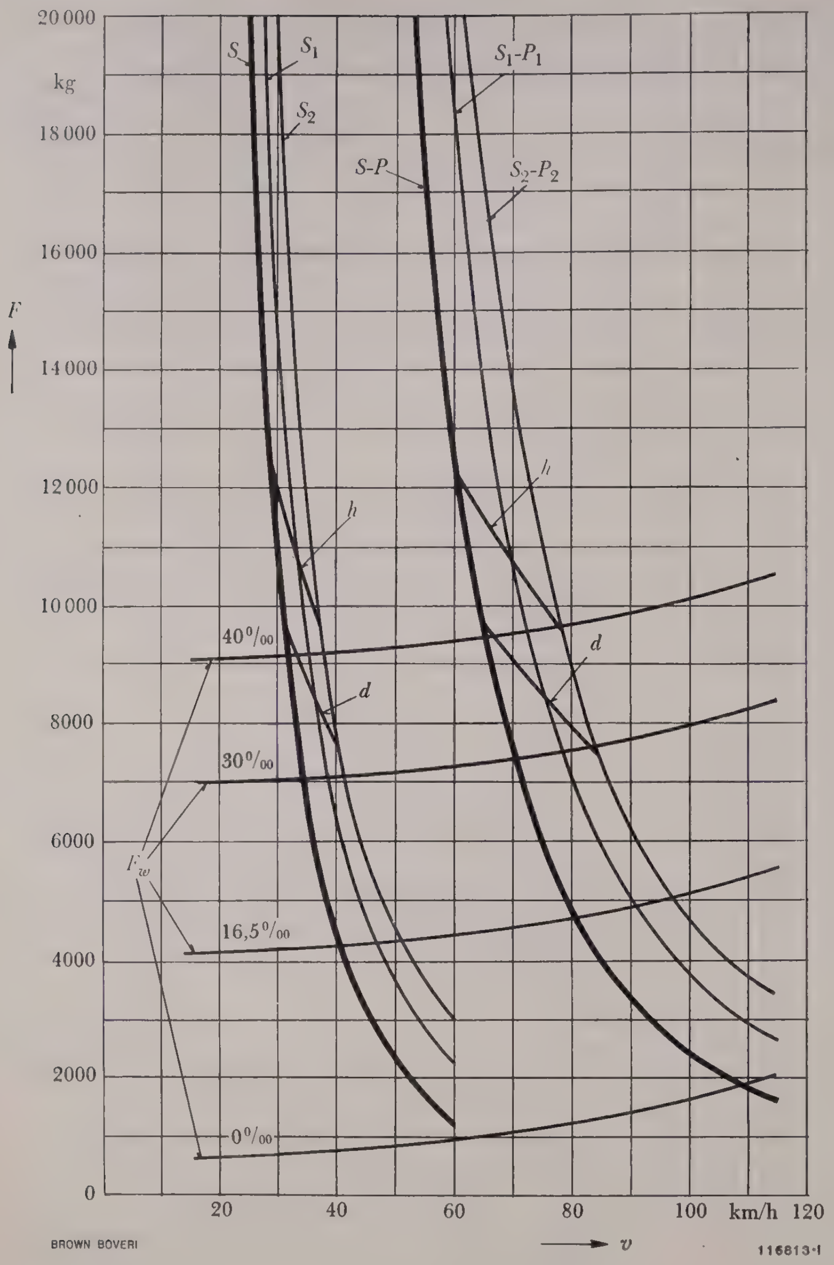


Fig. 5. – Diagram of tractive effort against speed for a line voltage of 3000 V d.c. and a wheel diameter of 965 mm

S = Four motors connected in series with full field

S_1 = Four motors connected in series with reduced field (field current = 0·75 × armature current)

S_2 = Four motors connected in series with reduced field (field current = 0·60 × armature current)

S–P = Four motors connected in series-parallel with full field

S_1–P_1 = Four motors connected in series-parallel with reduced field (field current = 0·75 × armature current)

S_2–P_2 = Four motors connected in series-parallel with reduced field (field current = 0·60 × armature current)

F = Total tractive effort at wheel rim in kg

F_w = Resistance of a combination consisting of motor-coach with luggage compartment, trailer coach and motor-coach, for various gradients (‰ = 0·1%)

v = Speed in km/h

d = Continuous operation

h = One-hour operation

Starting and Braking Resistors

The starting and braking resistors are mounted on the roof of the motor-coaches. The resistance elements consist of corrugated chrome-nickel strips stretched between special insulators held in a metal frame (Fig. 9). The resistance elements were amply dimensioned in order to permit constant speed over long distances downhill. This system of regenerative braking greatly reduces the wear of the brake shoes.

Protection

Two lightning arresters with Resorbit non-linear resistors protect the 3000-V high-voltage d.c. circuits against atmospheric over-voltages.

The traction motors are protected against overloads by over-current relays in both circuits. Should the supply voltage drop along the contact wire, an under-voltage relay with time-lag will trip the line circuit-breakers.

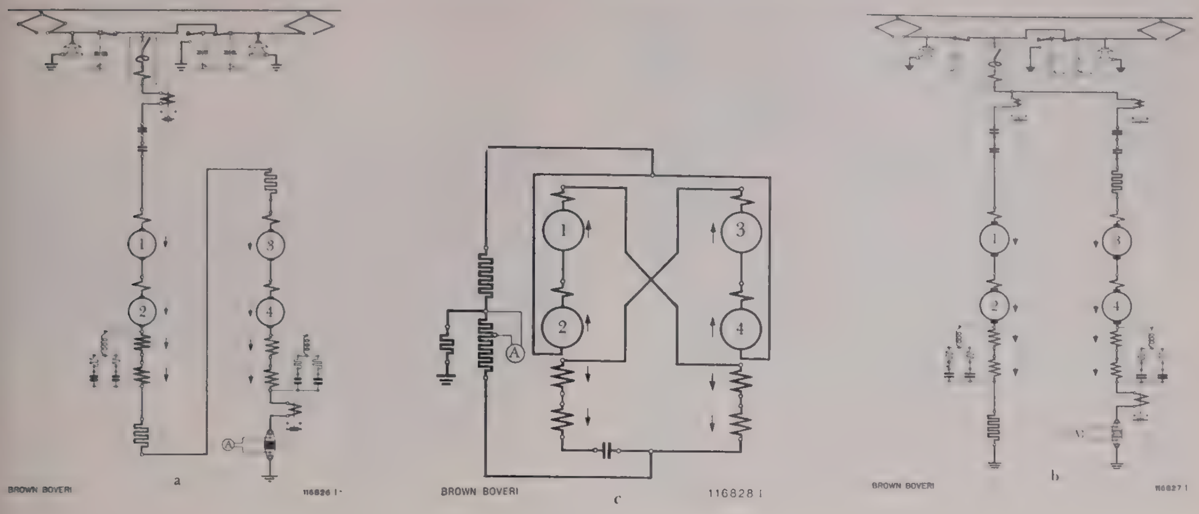


Fig. 6. – Basic circuit diagram

a: Series connection b: Series-parallel connection c: Braking 1, 2, 3, 4 = Traction motors

An electromagnetically operated circuit-breaker protects the high-voltage equipment against short circuits.

Auxiliary Equipment

The lighting, signal and control circuits, as well as the compresser set, are supplied from a monobloc converter which is connected in parallel and buffer with 65-V storage battery having a capacity of 192 Ah.

The converter set is ventilated by fans on both shaft extensions, which draw in air from behind the louvres in the sides of the motor-coaches. The air flowing axially along the set provides adequate cooling of the machine. Some of the cooling air leaving the converter is ducted to the various switchgear cubicles where it is used for cooling the apparatus and for the removal of ionized air, while the slight excess pressure inside the cubicle helps to keep out dust. A two-stage reciprocating compressor supplies compressed air at 8 kg/cm^2, which is required for the pneumatic brakes, the operation of the doors, etc.

Lighting and Heating

The lighting for the whole train is controlled from the driver's cab by a main contactor. Ordinary

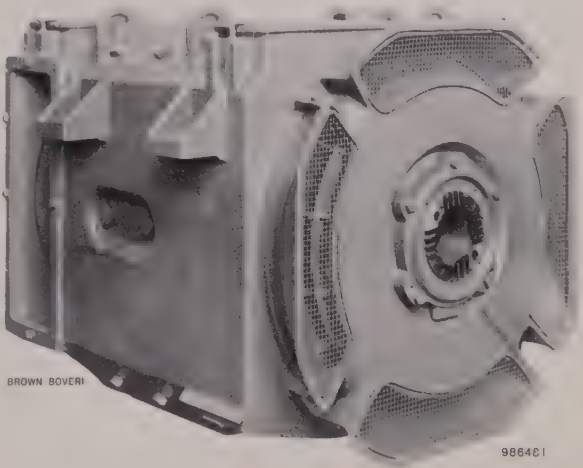


Fig. 7. – Traction motor

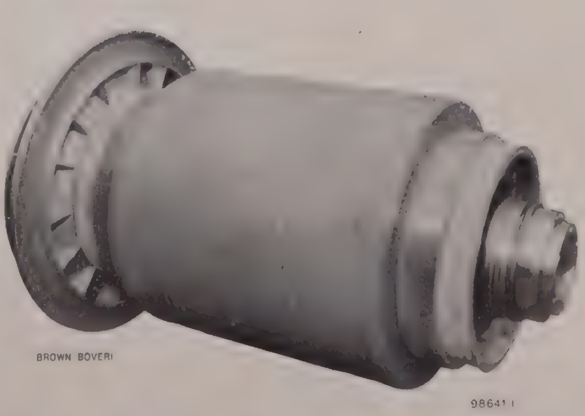


Fig. 8. – Rotor of a traction motor with double commutator

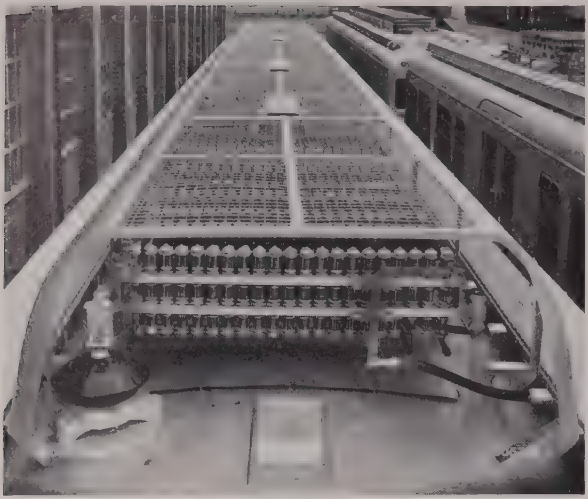


Fig. 9. – Starting and braking resistors with protective enclosure

In the foreground one of the two lightning arresters.

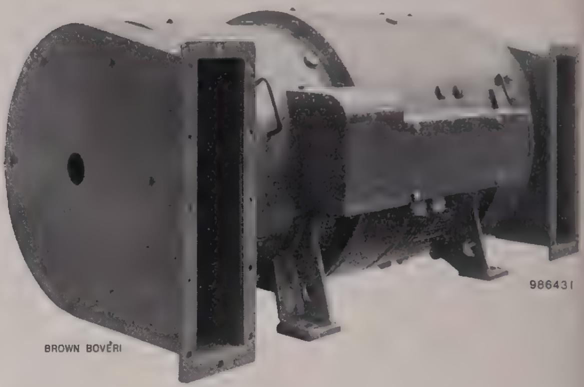


Fig. 10. – Converter set

On the left the connection flange for the cooling-air inlet ducting.

32-V tungsten filament lamps are used, connected as pairs in series.

The electric heaters are controllable in two steps and supplied directly at the line voltage. The radiators are arranged along the inside of the coach walls, which simplifies erection and maintenance.

Heating and lighting requirements of the trailer coach are supplied from the motor-coach with luggage compartment. The heating current is connected from one coach to the other by means of a single-pole jumper for 3000 V d.c. which was developed by Brown Boveri and has given excellent results in service.

The commissioning of these new multiple-unit trains marks a significant step in the efforts of RENFE to provide a safe, efficient and comfortable means of transport for their passengers and to compete with the traffic on the roads. The first operational results of these multiple units are very good and satisfy, or even exceed, the requirements made by RENFE in their specifications.

(AW) F. SAEZ

AIR-CONDITIONING EQUIPMENT IN RAILWAY VEHICLES

625.23 : 628.8

The various arrangements and features of air-conditioning installations are described. The first plant supplied for the panorama coach As 4ü 2802 of the Swiss Federal Railways is discussed in detail. Here, warm-air heating equipment is involved, combined with parts of a conventional air-conditioning plant. The favourable experience gained with the new arrangement led to an order for the air-conditioning equipment for four "Trans Europ Express" trains (TEE), belonging to the Swiss Federal Railways.

THE INTRODUCTION of luxury coaches has heralded the employment of air-conditioning equipment in rolling stock. The duties of such an installation are:

- To ensure throughout the year an adequate replacement of vitiated air by the introduction of filtered outside air, without causing draughts.
- To heat the coach to a comfortable temperature when it is cold outside.
- To lower the inside temperature and reduce the relative humidity of the air when ambient temperatures are high.

No attempt is made to humidify the air, since the cost would far outweigh the success likely to be achieved.

Fundamental Design of Air Treatment Equipment

Simplified Arrangement

The most straightforward equipment simply heats the air. Individual railway authorities have made extensive use of this kind of equipment in all classes of coaches following the acceptance of the principle that it is essential, at all times of the year, to provide an uninterrupted, draught-free supply of fresh-air. Installations of this nature completely satisfy requirements with respect to fresh-air renewal and heating. Dehumidification of the air and cooling in summer, however, can be achieved only to a limited extent, in so far as the supply of large quantities of outside air renders this possible. Such installations are hardly—if at all—more expensive than straightforward heating by means of heating elements combined with natural exhausters on the coach roof.

Complete Air Conditioning

Complete air-conditioning equipment for railway coaches consists of the following principle components:

1. *Cooling Section*

This is essentially the same for every present-day design of plant. Gas is compressed in a compressor, raising its temperature. Subsequently the gas is cooled and condensed at constant pressure in a cooler employing, for instance, air from the surroundings as a cooling medium. The condensed gas is now conveyed to the evaporator, whose coils are located in the stream of air which is finally delivered to the compartment. Immediately before the cooling medium enters the evaporator, however, it passes through an expansion valve in which the gas pressure is reduced to the pressure obtaining on the suction side of the compressor. At this reduced pressure the gas rapidly evaporates on its way through the evaporator, extracting the heat of evaporation from the room air passing over the outside of the evaporator tubes.

2. *The Heating Section*

In this section, similar to straightforward heating installations, it is necessary to discriminate between two main groups:

a. Direct heating, with which heating elements installed in the coaches heat the surroundings by radiation and convection.

b. Indirect heating systems in which the heating elements, usually combined to form a unit somewhere in the coach, transfer their heat to a medium such as water which is circulated through radiators installed in the passenger compartments; these radiators impart their heat by means of radiation and convection.

Direct heating, as well as indirect heating with hot water, has the disadvantage that the particles of dust on the heating elements get heated; moreover, the vitiated room air is always heated locally to a relatively high temperature. Both methods are unhygienic. A further disadvantage is that the heaters and radiators are always in the way when the compartments have to be thoroughly cleaned. Other disadvantages of hot-water heating are the increased weight and the inertia of the system, which can be very unpleasant when starting-up and when passing from a warm-air to cold-air zone, for instance, in the Alps. On the Gotthard line fluctuations of 12 ° C have been measured within ten minutes.

The disadvantages mentioned are eliminated when filtered fresh air is used as the heating medium. Moreover, with warm-air heating it is possible at all times of the year to change the air without draught: this is not the case with hot-water systems—unless additional ventilating equipment is installed, with an air heater for the winter months.

Brown Boveri have always been interested in train heating. The virtues of warm-air heating were recognized at an early stage and development work was concentrated mainly on this modern form of heating. The present-day Brown Boveri system of hot-air heating is distinguished by reliability, simplicity, ready adaptability and the low cost of operation and maintenance.

3. *Air Treatment and Circulation*

The various arrangements differ considerably with regard to the method of conveying the air and in the number of points where the air is treated, also in the location of these points in the air circuit.

In conventional air-conditioning plants air enters the compartment from the roof. The supply air is normally made up of one-third fresh air and two-thirds return air, which is extracted from the compartment and returned to the conditioning plant. This is usually accommodated in the roof space and contains the filters for fresh and return air, the cooler (evaporator) and the air heater for winter duty, also the necessary changeover dampers with their drive. To ensure that the compartment is not over-heated near the roof while the floor-level temperature remains low, the air heater is built to handle only about half the heating requirements; the remaining half is provided by heaters installed at floor level; these are either in the form of electric heaters or hot-water radiators.

So far, the classical air-conditioning system has won the widest popularity, and Brown Boveri have supplied such systems for the widest variety of vehicles, sometimes with the most difficult installation conditions.

With another type of air-conditioning plant, the supply air is delivered underneath the windows from a floor duct; with this arrangement the air velocity is selected so that the air always rises to the roof against the outer walls, whence—as with conventional layouts—it flows through the compartment. At the central station, where the air is prepared, only a small quantity of air is filtered, heated or cooled; for instance, the fresh-air component of the supply quantity. The unfiltered, recirculated air component is induced secondarily in nozzles in the compartment as the primary air is admitted. When cooling, however, it is not possible to introduce the small amount of treated outside air into the compartment with an adequate temperature difference, because the surface temperature of the evaporator would have to be below freezing point and would freeze up in consequence. For this reason secondary air-treatment units are installed beneath the compartment windows and these exert an influence on the entire mixture of air.

The advantage of this system is that the air ducts and primary air-treatment equipment need only be proportioned to handle the fresh-air component, i.e. about one-third of the total air quantity. Offsetting this advantage is the considerable outlay for secondary-air units and the supply to them. In addition, up to window level, these units reduce the free width of the compartment. In coaches where the individual compartments are connected by a corridor there is insufficient balance of temperature between compartments having different numbers of passengers; this is because the decisive effective number of air changes is three times less than with other kinds of systems. This circumstance is taken into account by installing in each secondary air-treatment unit appropriate regulating gear, which the passenger can adjust for controlling the temperature according to the number of passengers travelling in the compartment and to other disturbing influences. The passenger, however, will gladly forego this adjustment feature provided comfortable conditions are maintained automatically. Since in such installations the control of temperature is left solely to the passengers, and is not automatic, the system is not disturbed by open windows. All other factors having a disturbing influence on the temperature, such as the already mentioned varying number of passengers and the changing outside conditions, are not automatically accommodated by the system either and must always be offset by manual adjustment of the regulating devices. The question, whether or not the balance of an air-conditioning system is upset by open windows is not dependent upon the plant design, but solely upon whether the compartment temperature or simply the supply-air temperature is automatically controlled. The Company have recently developed a new design. In essentials, the equipment is a combination of modern warm-air heating and components from a conventional air-conditioning plant. Details of this arrangement are furnished in the section beginning at the bottom of page 636.

Power-Supply Problems Associated with Air-Conditioning Plants

The problems of supplying power to air-conditioning plant are extremely diverse and frequently more difficult than installing the equipment. A number of arrangements can be employed, depending on the purpose of the vehicle and the operational duty for which it is visualized.

In electric motor-coaches and multiple-unit compositions, power is usually obtained from the overhead wire; with diesel-engine propulsion this energy is provided by diesel-electric sets or by generators driven by the main diesel engine. In the case of trailer coaches, diesel-electric units in each coach provide the highest degree of adaptability. For complete trains made up of matching coaches these units can be assembled in a special luggage-carrying motor-coach. Both solutions require a considerable amount of maintenance and frequent checks. A most difficult problem, but one which may not be neglected, is subduing the noise of single-coach units. In railway networks employing only electric traction, energy can be obtained for the entire air-conditioning plant from the motor-coach, by way of the normal heating jumpers. This method of supplying the motors cannot be considered, however, if a unified supply system is not available, because the cost of conversion and switching over for each individual coach would be prohibitive. The disadvantage with this arrangement is that the air-conditioning plant can only be in operation when an occupied train is being hauled.

A solution which has been most widely accepted is a combination employable in individual coaches. With this method the electrical energy to all the motors driving the compressors, fans, etc., is supplied by a generator driven by one of the coach axles. The same generator, having an output of approximately 25 kW, charges a battery which can run the plant for some time—usually about three hours—during periods of standstill. For longer waiting periods a three-phase motor supplied from the mains is used to drive the generators. When the coaches are standing still, the generator is decoupled from the driving coach axle by a centrifugal coupling.

The energy required for heating is always taken from the normal heating connections; these can convey steam or electrical energy. There are also ways of generating the heat energy additionally by means of oil burners. During seasonal changes and on cool summer days, when heat energy is not flowing in the supply lines, limited heating is possible by means of the electrical energy intended for cooling, which is supplied by the axle generator. Such equipment conduces to unhampered employment of the coach for the greater part of the year, regardless of the extremely wide differences in voltages and heating steam unfortunately encountered with international through traffic. If it is desired to run the coaches without restriction throughout the year, it is necessary for the heating section of the air-conditioning plant to comply with the requirements of the RIC[1] applying to normal heating equipment. According to this specification the heating system can be supplied with the following heating media:

1000 V a.c., 16⅔ c/s or 50 c/s
1500 V d.c. or a.c., 50 c/s
3000 V d.c.
steam at 1 to 7 kg/cm²

The voltages may deviate by ± 25% from the rated values. Experience proves, however, that the deviations are frequently much greater. The changeover from one form of supply to the other can take place slowly or quickly; there is not always an interval in between, when current does not flow.

The Company have always built reliable switchgear for dealing with this problem of switching over. The switchover was carried out previously by means of a manually operated switch, a feeler system ensuring that the switch position coincided with the available heating medium. But long before the last war, Brown Boveri supplied automatic voltage-selecting devices whose feeler system controlled the switchover direct, instead of merely supervising it. Brown Boveri voltage-selecting devices have attained a high degree of reliability and have been accepted by the state railways of a very large number of countries.

Equipment in the Panorama Coach As 4ü 2802 of the Swiss Federal Railways

The panorama coach (Fig. 1) must conform with severe requirements since it is employed exclusively for international duty. Brown Boveri contributed the complete air-conditioning plant, together with controls, lighting, power-supply and ancillary gear.

These components were designed with the object of running the coach in a perfectly normal manner—even abroad, without carrying additional technical staff and without instructing the kitchen staff likely to be travelling on the train. Care was therefore taken to provide the simplest and most reliable arrangement of the individual parts and to eliminate the need for any form of attention, apart from closing a main switch when starting, as in all normal coaches. By comparison with the designs employed till now, some of the solutions are fundamentally new.

The cooling part of the air-conditioning plant is built to handle 15 000 kcal/h under extreme ambient conditions, such as those encountered in Southern Italy. The high-speed compressor and the condenser are built as an aggregate and have a common motor. This aggregate also embodies the receiver, filters, supervisory equipment, etc., and is suspended under the floor of the coach, Fig. 2.

The coach is extremely restricted in height and the space available in the arch of the roof is accordingly small (Fig. 1). For this reason, two roof units are provided, one at each end of the coach; each is capable of handling half the cooling load. These roof aggregates consist of fan, air cooler and an air heater for limited heating from a 72-V supply network in the event of the primary heating medium not being available.

The entire heat requirement of the coach is supplied exclusively by warm air. The heating aggregate, consisting of fresh-air fan, filter and air heater (suitable for duty with multi-voltage electrical supply, also with steam), corresponds to the standard equipment installed in coaches employed internationally. This aggregate is suspended beneath the floor, approximately in the middle of the coach. The associated switchgear is also of standard design; this consists of the h.v. switchgear together with the associated feeler system for selecting the voltage according to the various supplies, and the equipment for controlling the fresh-air fan. In the event of a failure of any of the normal heating media, limited heating is available—as already mentioned—from the small air heaters in the two roof units; current is provided by one of the axle-driven generators or the accumulator. Usually, however, i.e. as long as the heating medium is available from the

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[1] Regulations governing the reciprocal use of carriages and brake-vans in international traffic.

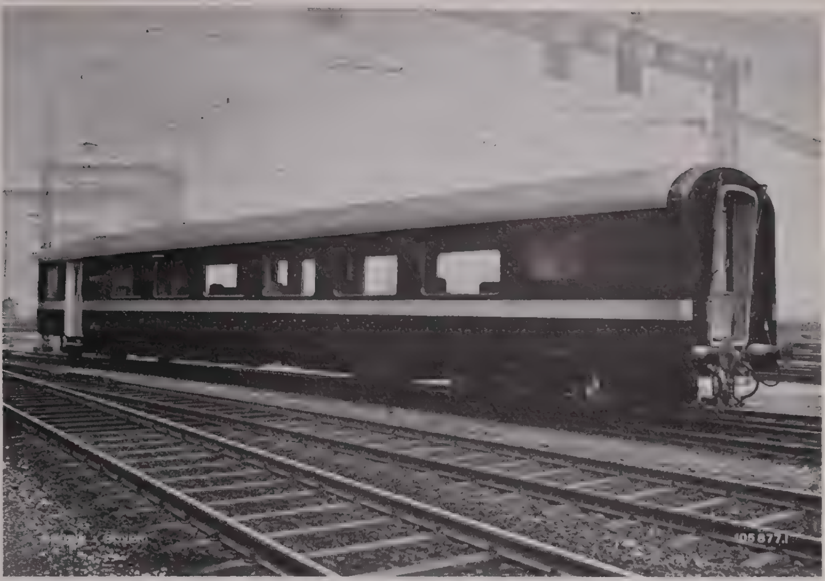

Fig. 1. – Panorama coach As 4ü 2802 belonging to the Swiss Federal Railways

constructed of light metal and having a reduced height from floor level to ceiling. The Swiss Industry Company, Neuhausen, built the actual coach.

normal source, the two small air heaters remain inoperative.

The air circuit for heating duty is the same as for a modern warm-air heating system. The outside air is introduced at window height via the side walls and is conveyed by a fan through the high-efficiency filter and the steam or electrically heated air heater to the distributing ducts inside the coach (Fig. 3). From the distributing ducts the warm air is delivered uniformly along the entire length of the compartment, thereby forming a layer of warmth along the side walls and the windows. This method of distribution effectively combats condensation on the windows.

A second air circuit is provided for cooling duty. Return air is drawn from above floor level at the ends of the coach and delivered via filters to the roof units. The extended floor ducts belonging to the warm-air heating system convey the outside portion of the supply to the roof units also, thereby preventing direct delivery into the coach. If necessary, the roof units cool the mixture of fresh and return air and then deliver it to the compartment via the perforated ceiling (Fig. 4). All the changeovers in the air circuit, dictated by the various operating conditions, are carried out without changeover dampers. This may well be the first design of air-conditioning

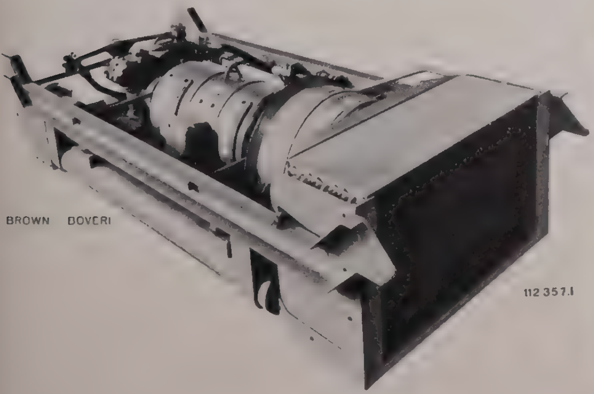

Fig. 2. – Compressor-condenser aggregate, 15 000 kcal/h

From left to right: Compressor, driving motor, condenser fan, condenser. The cylindrical receivers below the aggregate form the part of the framework.

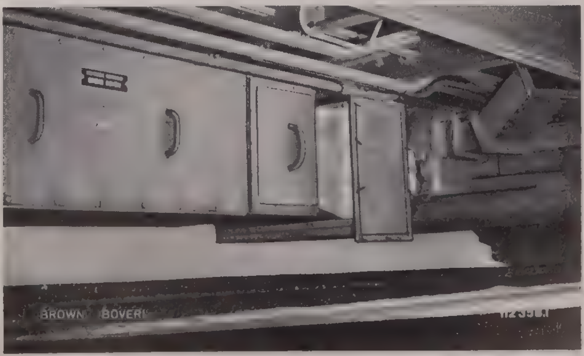

Fig. 3. – RIC heating aggregate, 35 kW, beneath the coach floor

From right to left: High-efficiency filter casing, air heater for operation with steam and multiple electrical voltages. On the extreme right part of the compressor aggregate can be seen.

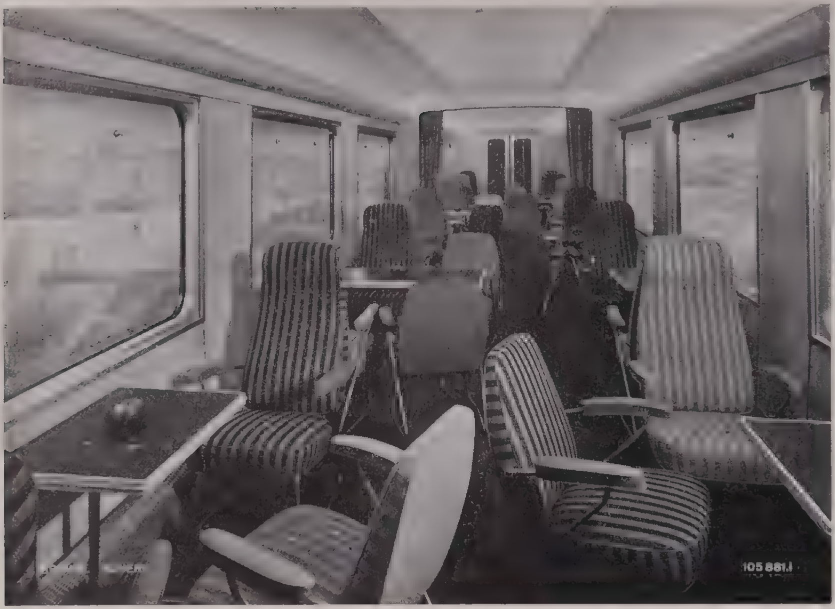

Fig. 4.–Panorama coach As 4ü 2802 belonging to the Swiss Federal Railways

Above, the perforated ceiling.

At the sides, above the windows, the indirect tubular lighting.

At the left, below, the warm-air distributing duct is visible.

plant having to deal with a widely varying air circuit which dispenses with changeover dampers and their drives. As far as possible, the discharged air is used to condition neighbouring compartments, and special gear, such as exhaust air fans, are not provided. A slight plenum is thereby maintained throughout the coach; this prevents the ingress of unconditioned air through crevices and the disturbing influence on the automatic temperature control caused by open windows is prevented to an advanced degree.

Control is by means of a multi-stage, return-air thermostat developed by Brown Boveri specially for the duty involved. This instrument, which is provided with conventional switching contacts, passes the various commands to the air-conditioning plant: heat-up; heat; ventilate with safeguard against draught; ventilate without air heating; slight cooling; full cooling. The desired temperature rise in the compartment during the milder seasons of the year is achieved by grading the individual switching stages. If, by way of an exception, this temperature rise should prove inadequate, the level of the entire regulation can be adjusted within wide limits by resetting the thermostat—as with every normal heating system.

When the heating is in operation the temperature in the supply-air heating duct is controlled by a standard contact thermostat with respect to the outside temperature, so that warmer air is introduced at lower outside temperatures. Control is achieved by intermittent switching. This form of control is characterized by rapid adaptability, without over-compensation of the coach temperature. The simple construction conduces to extreme dependability; furthermore, it is possible for ordinary railway staff, without special training, to carry out checks and also repairs if necessary.

The energy for heating is supplied from the heating jumpers conveying one of the five voltage (and corresponding current values) specified by RIC, or steam. For limited heating, when the main heating supply fails, for driving the compressor aggregate and the fan, also for the lighting and kitchen equipment (hot-plate, hot-water heater and cold box), the energy is supplied by a 25-kW generator driven from one of the coach axles. The battery, which is charged from the same generator, allows full operation to be continued for more than three hours while the coach is stationary. For longer periods of standstill, a three-phase motor is provided to drive the generator.

The air-conditioning plant in the panorama coach As 4ü 2802 of the Swiss Federal Railways is characterized by the following features:

- Simple construction of the plant components and controls, conducing to extreme reliability and the virtual elimination of maintenance.
- The same heating section as that employed in more than one hundred normal coaches employed on international runs.
- The entire heating output is supplied by a central air heater; for international duty, this feature is particularly desirable when switching over. Except during special operation, when the normal heating medium is not available, only fresh air is passed over the heater elements. From a hygienic point of view, this constitutes an advance.
- Separate fresh-air fan and no exhaust fans. This arrangement ensures a slight plenum in the coach and opposes the ingress of unconditioned air, which is accompanied by draughts and dirt.
- In the event of a fault developing in the cooling or heating section and the associated air circuits, the other part remains fully operative.
- In spite of a widely varying air circulation, dampers and the associated driving gear are not employed.
- Modest space requirements in the compartment. Ready accessibility for cleaning the compartment and the equipment.
- No openings in the roof of the coach because all the components are installed from below; accessibility for maintenance is assured. This is an advantage from the coach-building point of view. In addition, the danger of accidents caused by touching the overhead wire when carrying out checks on electrified lines is eliminated.

Now that the coach equipment has proved itself during two years of duty, the new design may be regarded as representative of future trends.

Future Considerations

Based on the good results experienced with the equipment in the panorama coach As 4ü 2802, four Trans Europ Express trains owned by the Swiss Federal Railways are now being equipped with air-conditioning plants which operate on the same system. It is possible, however, to simplify the arrangement somewhat, because a three-phase network supplied from the motor-coach is available throughout the train for driving the motors. In this case too the energy for heating is obtained from the normal heating connections, but with only 1500 V, 16⅔ and 50 c/s, a.c., also 1500 V and 3000 V, d.c., according to the voltage in the overhead line. The low-voltage air heaters belonging to the roof units are also dispensed with, so that only one air heater for all duties is installed in each coach. Under no operational condition is air from the compartment heated by any other kind of air heater or element.

It is to be expected that air-conditioning plants will first be installed increasingly in dining cars and other coaches with more than average comfort. The general introduction of air-conditioning plants, at least in first-class compartments, may well depend largely upon whether it is possible to build simple installations whose initial costs are favourable; decisive though, will be the ability to provide equipment which requires a minimum of attention and maintenance. An essential step in this direction has been achieved with the new design of air-conditioning installation described here.

(FJH) F. THOMANN

TRACTION VEHICLES FOR RACK RAILWAYS

621.335:625.33

After briefly reviewing rack railways in general, with particular reference to fast, lightweight motor-coaches, the author describes some new units equipped with Brown Boveri gear for rack railways.

WITHIN the extensive field of electric traction, rack railways occupy a rather special position. Although they are identical with other railways in many respects, they possess a number of individual features peculiar to rack railways, which demand special technical treatment.

From the transport aspect rack railways may be subdivided as follows:

- Those of a main-line character.

These are an integral portion of an extensive network and carry through traffic over mountain ranges. The traction vehicles are usually intended for mixed adhesion and rack operation. Frequently the track is made narrow-gauge owing to the small radius of many of the curves. Typical examples are the Brünig line in Switzerland and the Transandine Railway in Chile.

- Those of a branch-line character.

These carry local and tourist traffic in mountainous areas. As a rule the line is supplemented with a rack bar along certain sections and the vehicles are designed for mixed adhesion and rack operation. A typical example is the St. Gall–Gais–Appenzell–Alstätten line in Switzerland.

- Mountain railways.

These run from a station in the valley up to the summit of a mountain or some vantage point and are almost solely used for tourist and sport traffic. In most cases these railways are rack throughout and have no adhesion sections. An example is the Rigi line in Switzerland.

The question of whether electrification of a rack railway is worth while is hardly ever posed nowadays. Apart from all other known advantages of electric traction, the particularly important requirement of rack railways, with their very steep gradients, namely that a high driving power should be accommodated in the minimum of space and, especially, with the minimum of weight, can only be realized with electric drives. Furthermore, a reliable, efficient downhill brake is easily realized with electric traction.

A variety of supply systems are employed by railways of this kind. The rack railways of main-line character normally have the same supply as used by the level sections of the same network, e.g. single-phase a.c. at 15 kV, 16⅔ c/s on the Brünig line and 3000 V d.c. on the Transandine Railway. Other rack routes are mostly supplied with d.c. at a voltage between 600 and 1500 V, or with single-phase a.c.; the use of three-phase a.c. is, however, not unknown.

Although the three-phase system may be considered obsolete for main-line electrification, mainly on account of the rigid characteristic of the motors and difficulties with the contact wire in stations, it is nevertheless being used in a number of cases of recently built rack railway installations, particularly mountain railways. The single track of such lines presents only slight difficulties in the erection of the double-pole contact wire. The rigid characteristic of the motors is not a drawback on lines with an almost constant, steep gradient. The traction motors and, indeed, the whole of the electrical equipment, are very simple. An efficient downhill brake is obtained without additional expense, because the motors, on exceeding their synchronous speed, act as generators and return the excess power to the supply system.

The greatest disadvantage of the three-phase system for mountain rack railways is the fact that the speed is practically the same uphill and downhill. Generally speaking, with modern vehicles, it is possible to achieve much higher speeds uphill than downhill, because the speeds in the latter case are usually severely restricted for safety reasons (see Table opposite). The need for running at equal speed, due to the induction motor, consequently prolongs the travelling time to a marked extent, compared with other systems. On routes with very varied gradients the conditions are still less favourable because the speed must be reduced to the figure admissible for the downhill trip on the section with the steepest gradient.

Whereas main-line rack railways extend their rolling stock by purchasing locomotives or motor-coaches, depending on their particular requirements, hardly any new locomotives are being built for the other types of rack railways. The passenger traffic on these routes is carried as far as possible by lightweight motor-coaches.

Maximum admissible downhill speeds according to Swiss regulations

Gradient	%	13	15	17·5	20	25
Max. speed	km/h	18	16·5	15	14	12

The use of lightweight motor-coaches allows the weight of vehicle per passenger to be reduced to a minimum. This weight reduction allows higher speeds to be attained, which is particularly advantageous for mountain railways, the majority of whose passengers are skiers who wish to be taken uphill several times a day.

Two characteristic examples of how the performance of a line can be improved by employing

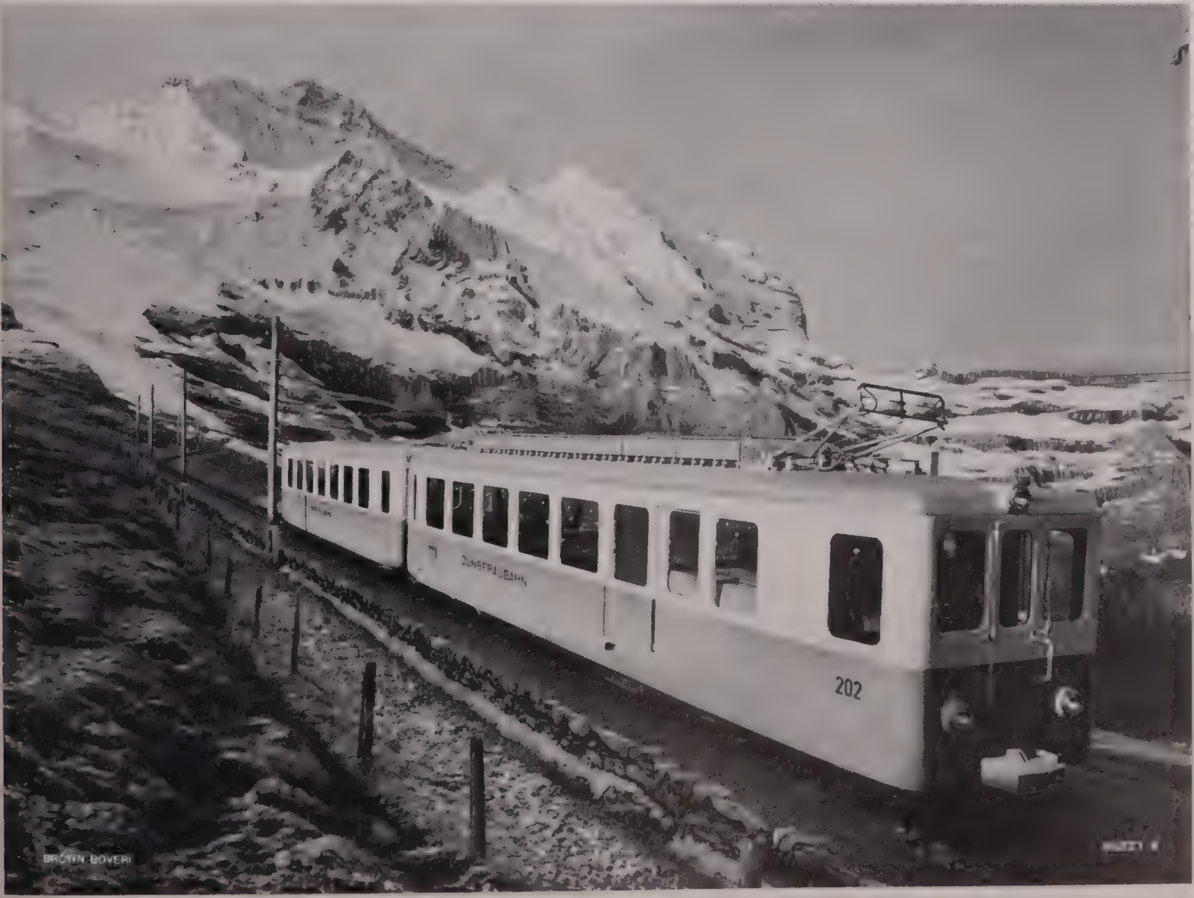

Fig. 1. – Motor-coach train of the Jungfrau Railway for three-phase supply at 650 (1125) V, 40 (50) c/s

Rack operation throughout, gauge 1 m, maximum gradient 25 %, one-hour output 600 hp, top speed 25 km/h. Capacity 143 passengers and luggage.

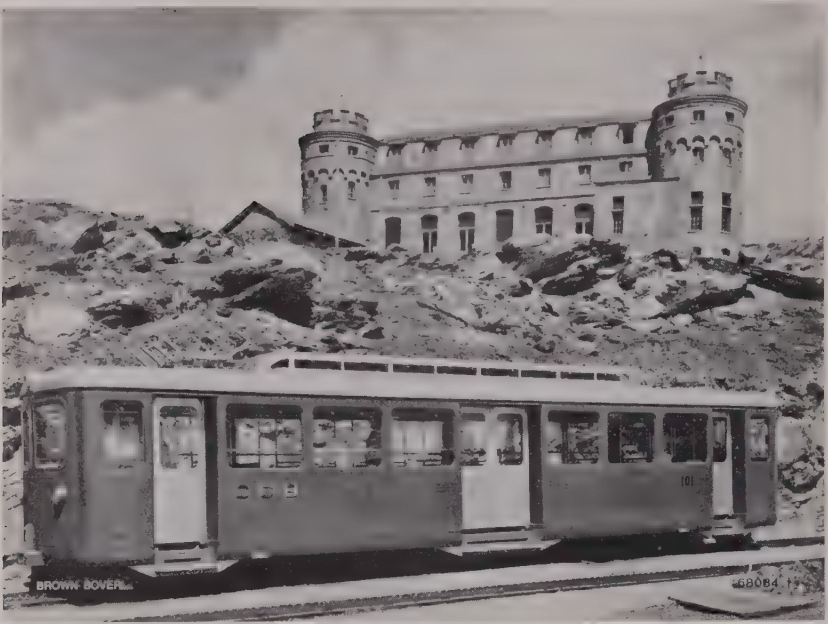

Fig. 2. – Motor-coach of the Gornergrat Railway for three-phase supply at 750 V, 50 c/s, at the summit station

Rack operation throughout, gauge 1 m, maximum gradient 20 %, one-hour output 260 hp, top speed 15·2 km/h, capacity 110 passengers.

lightweight motor-coaches are afforded by the renowned Swiss mountain railways up the Gornergrat and to the Wengernalp. The old locomotives of the Gornergrat railway, with a tare weight of about 23 t and a one-hour output of 250 hp, were able to haul trains carrying 110 passengers and developed an average speed of 8·5 km/h. The new lightweight motor-coaches, which always run solo, are capable of carrying the same number of passengers, weigh only 17·5 t empty and can attain an average speed of 14·4 km/h due to the reduction in weight and better utilization of the drive power. The same result was achieved with the Wengernalp line. For the same tare weight and passenger capacity, the new trains of this line (comprising one motor-coach pushing a passenger coach) possess double the power of the old trains with locomotives and have raised the speed from 8·5 to 17·8 km/h.

Similar conditions may be met on the Jungfrau Railway, the highest railway in Europe. The lightweight motor-coaches have enabled the speed to be considerably increased on this line too.

The excellent results obtained and steadily increasing traffic have induced these mountain railways to give a number of repeat orders for lightweight traction stock. At the present moment there are twelve units of the Gornergrat line, eleven of the Wengernalp and six of the Jungfrau line on order or in service. The electrical equipment of these vehicles was built by Brown Boveri, the mechanical part being designed by the Swiss Locomotive and Machine Works, Winterthur.

Fig. 1 shows one of the trains of the Jungfrau Railway at a point on the route, while Fig. 2 shows a motor-coach of the Gornergrat line at the summit station. Detailed descriptions of these vehicles have already been published in the Brown Boveri Review [1, 2].[1]

While on the subject of recently delivered lightweight motor-coaches for rack railways, mention may be made of the d.c. motor-coach for combined rack and adhesion operation on the Rheineck-Walzenhausen line in Switzerland (Fig. 3). This commenced service in 1958. Brown Boveri designed and supplied the electrical equipment, the mechanical part being built by the Flug- und Fahrzeugwerke Altenrhein (FFA) and the Swiss Locomotive and Machine Works (SLM). A brief description of this vehicle follows later in this article.

The latest design in the sphere of rack mountain railway stock is probably the shuttle-service train of the Vitznau-Rigi Railway (Switzerland). This train, consisting of a d.c. motor-coach pushing a passenger coach, is at present being built. When

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[1] The figures in square brackets refer to the bibliography at the end of the article.

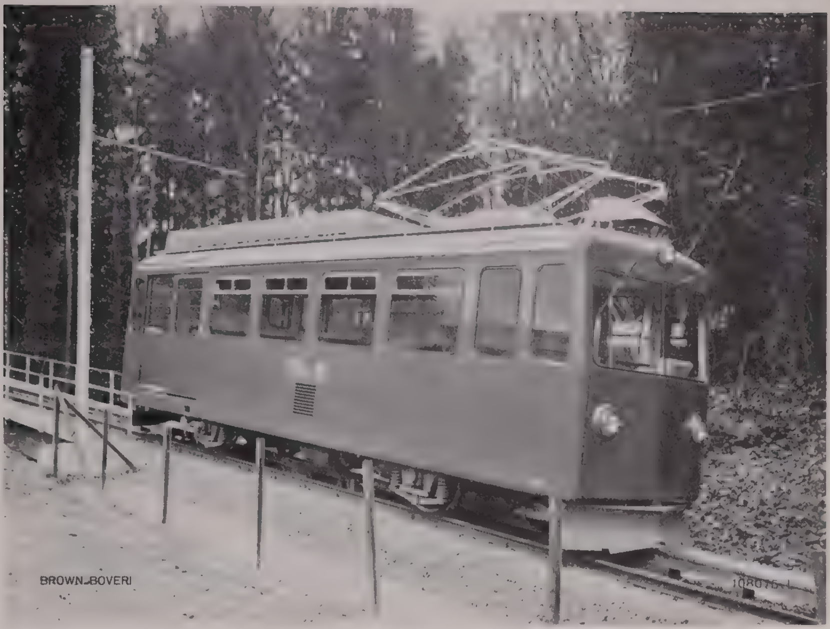

Fig. 3. – Motor-coach of the Rheineck–Walzenhausen line for 600 V d.c.

Mixed adhesion and rack operation, gauge 1·2 m, maximum gradient 25·25 %, one-hour output 288 hp, top speed 30 km/h, capacity 60 passengers and luggage.

finished it will have a passenger capacity of 260 persons and, due to the high installed power of roughly 1200 hp, will be able to attain a speed of about 23 km/h up gradients of 25 %. For this ultra-modern train of what was the first rack railway in Europe, this Company supplied the electrical equipment. A full report of this vehicle will be published at a later date.

Fast shuttle-service trains are also employed now on the rack railways with a branch-line character. The Stansstad-Engelberg Railway (Switzerland), for instance, is to discard its obsolete three-phase service and be converted on modern lines by the end of 1962. The line is being modernized, extended to Hergiswil, where it will connect with the Brünig line. The route will be re-electrified for single-phase current at 15 kV, 16⅔ c/s, permitting through traffic from Lucerne to Engelberg, without having to change. The rolling stock will comprise five shuttle-service trains for mixed adhesion and rack operation. For these trains, which are on order now, Brown Boveri are supplying the complete electrical equipment. Normally each train will consist of a motor-coach, a driver-trailer and a passenger coach in the middle, with space for 170 passengers and baggage. On the adhesion sections the train can haul two extra trailers if required. The one-hour output of the motor-coach is 1000 hp and the top speed 75 km/h. On the relatively short rack section, with its steep gradient of 25 %, the fully loaded composition will run uphill and downhill at 12 km/h.

Maximum safety for the passengers is a keyword when projecting new rack vehicles. Even under the most adverse circumstances it must be possible to stop the train reliably in the event of a breakdown. This is primarily the responsibility of the mechanical brakes, but the electrical equipment must also be designed accordingly. On the steep downgrades of a rack section the train cannot be braked with the conventional mechanical braking systems because they are only able to perform a restricted amount of work. For this reason an efficient electrical braking system is essential. Regenerative braking is advantageous on account of the power which is regained, but it suffers from the drawback that, if the supply should fail, the brakes are rendered ineffective. In order to be able to run downhill in the event of such faults, a rheostatic brake independent of the contact wire voltage is often employed. The passengers can thus be sure of reaching the lower station in safety, even if the supply fails.

A brief account will now be given of two interesting rack vehicles equipped by Brown Boveri: the motor-coach of the Rheineck–Walzenhausen line and the converted locomotives of the Jungfrau Railway.

Motor-Coach of the Rheineck-Walzenhausen line

To replace the old combination of funicular and tram service on the barely 2 km long line between Rheineck and Walzenhausen (Switzerland), a modern motor-coach designed for mixed rack and adhesion service was taken into service at the end of 1958. The line covers a difference in altitude of 271 m and is equipped for part of its length with a rack of the Riggenbach system. The maximum gradient is 25·25 %. The supply to the contact wire is at 600 V d.c., the complete substation was equipped by Brown Boveri, employing mercury-arc rectifiers.

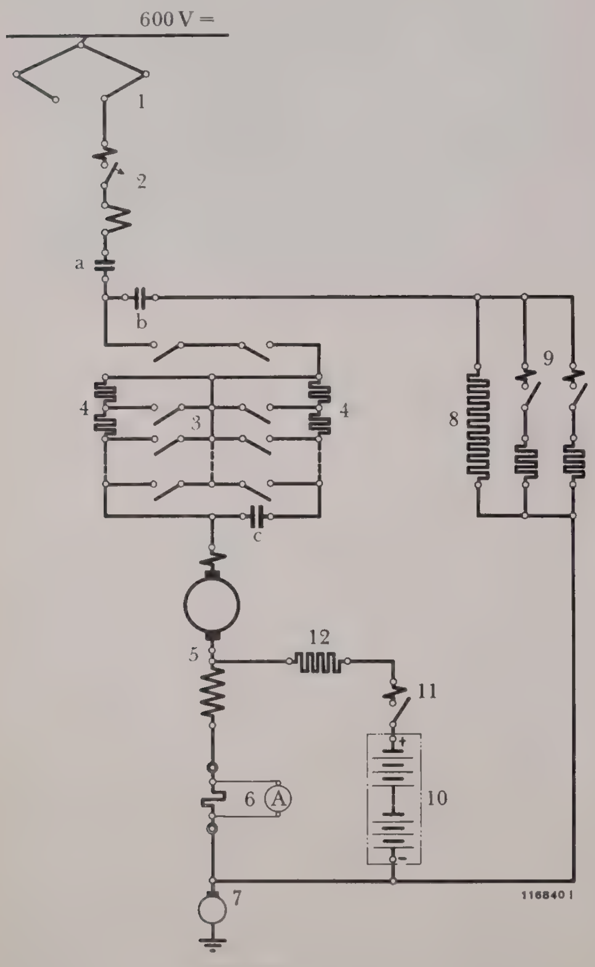

Fig. 4. – The main circuits for motoring and electric braking of the Rheineck–Walzenhausen motor-coach

To simplify the diagram only one of the controllers in the driver's cabs is shown. The second is parallel with it.

1 = Current collector
2 = Main breaker
3 = Controller (a, b, c, switching elements)
4 = Starting resistors
5 = Traction motor
6 = Motor ammeter
7 = Earthing brush

8 = Braking resistors
9 = Contactors for fine regulation of the brakes
10 = Battery
11 = Contactor for extra excitation during braking on adhesion
12 = Excitation resistor

An analysis of the local and tourist traffic proved that a single passenger and baggage coach, with space for 60 persons, would meet the requirements. The motor-coach ordered (Fig. 3) was tailor-made to the special conditions of the route. Its main data are as follows:

Type designation	BFhe 1/2
Gauge	120 cm
Overall length	10·7 m
Tare weight	14·76 t
Payload (60 passengers and luggage)	4·75 t
Number of seats	28
One-hour output	288 hp
Corresponding speed	19·5 km/h
Top speed	30 km/h
Number of motoring notches	14
Number of braking notches	21
Mechanical part supplied by	SLM and FFA
Electrical equipment supplied by	Brown Boveri

The two-axle motor-coach is equipped with a self-ventilated traction motor, mounted lengthwise, which, by means of a Cardan shaft, continuously drives the rack pinion rotating freely on the axle at the downhill end of the coach. On the adhesion section the pinion is coupled with this axle through a fluid clutch, supplied by SLM. On the rack section this drive is uncoupled, preventing the wheels from slipping on the rails. For the uphill journey with a gradient of 25 % the speed with an average load is 20 km/h, in which respect this vehicle may be considered the fastest of its kind, i.e. for lines with gradients exceeding 20 %. During the downhill trip the motor acts as a self-excited braking generator on to resistors. The schematic diagram of the main circuit is illustrated in Fig. 4.

The motor-coach has two driver's cabs for control by one man. The speed during motoring and braking is controlled by the direct controllers mounted in the two cabs. The associated resistors are mounted on the roof. A 36-V battery provides the current for control and lighting.

The unit is equipped with three mechanical hand-brakes and with an electric rheostatic brake. The functions of the various brakes are as follows:

- The gear brake acts on the gearing between the traction motor and the driving pinion. This brake can stop the fully loaded vehicle at any point on the rack section and hold it still. If the maximum admissible speed is exceeded on the downhill trip on the rack section, the gear brake is automatically applied by the action of the spring, bringing the vehicle to a stop. The same action is performed if the driver should become incapacitated, the brake being applied by the action of the dead-man's handle.
- The ratchet brake acts on the braking pinion which rotates freely on the axle at the uphill end of the coach. This brake is only operative during the downhill journey; in the opposite direction it can rotate freely. Before starting each uphill trip the driver has to apply the ratchet brake, so as to prevent the vehicle rolling back down in the event of a breakdown (e.g. failure of the power supply). This brake can also brake and hold the vehicle at any point on the rack section.
- The block-type brake for adhesion acts on all four wheels and can hold the vehicle on the adhesion section.
- The rheostatic brake is independent of the contact-wire voltage and acts as service brake during the downhill trip on the rack section. The electric brake can slow the coach down to 6 km/h. Owing to the large numbers of notches, it allows the speed to be maintained at the prescribed figure with great accuracy.

This motor-coach has been in regular service since December 1st, 1958, running 18 hours daily without interruption. Experience has proved that it has a high transport performance and a high standard of comfort. The time from Rheineck up to Walzenhausen is 6 minutes, while the downhill trip takes 8 minutes, so that the service is good and rapid.

Converted Locomotives of the Jungfrau Railway

At the end of 1960 the undertaking supplying power to the Jungfrau area is changing over from 40 to 50 c/s. Since the railway runs off a three-phase supply, the traction vehicles must also be adapted to the new frequency. At a later stage it is proposed to increase the contact-wire voltage from 650 to 1125 V.

Advantage was taken of this opportunity to modernize the four old locomotives, supplied by Brown Boveri in the years 1912–14 [3]. The conversion of the electrical equipment was entrusted to this Company and completed in the spring of 1960. From the functional aspect the electrical part has been newly designed and brought right up-to-date. Hence the equipment is now as good as new. Fig. 5 shows the opened equipment block of locomotive No. 10 as delivered in 1912, Fig. 6 the same block after conversion.

The increase of 25 % in the speed of the traction motors due to the increase in frequency had to be partly compensated by changing the gear ratio, in order to keep the speed of the vehicle within the limits stipulated as safe. This change in the gearing was made by the Swiss Locomotive and Machine Works in Winterthur.

The main data of the converted locomotives are as follows:

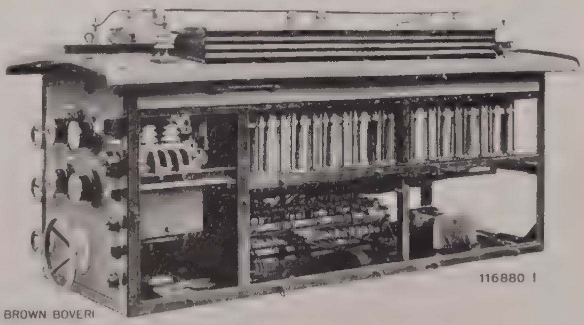

Fig. 5. · Equipment block installed in the locomotive No. 10 supplied in 1912 to the Jungfrau Railway

The notching resistors, oil circuit-breaker, tap changer and lighting transformer are visible when the side panel is removed. At the front end are the instruments and various controls.

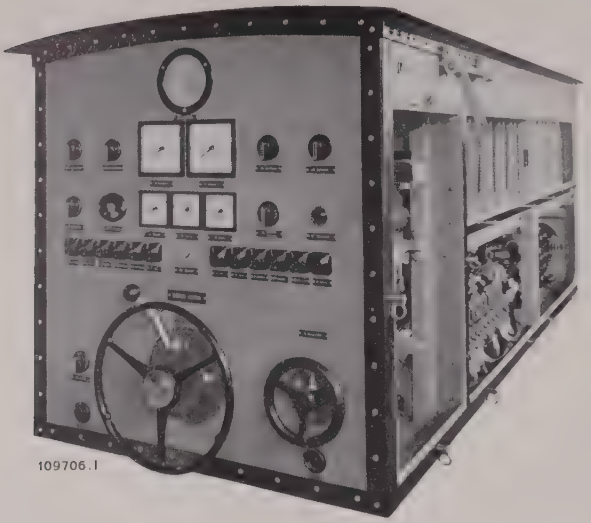

Fig. 6. – Equipment block of the Jungfrau locomotive after conversion

All the controls and instruments were modernized and mounted logically and neatly on the front end panel.

Number of locomotives	4
Type designation	He
Gauge	1 m
Maximum gradient	25 %
Overall length	5·16 m
Weight of locomotive	appr. 13 t
Total weight of train	35 t
Supply system	three-phase a.c.
Contact-wire voltage	650 V, later 1125 V
Frequency	50 c/s (for the present still 40 c/s)
One-hour output at 50 c/s	2 × 192 hp
Corresponding speed at synchronous speed of motors:	
On the "Slow" notch	9·5 km/h
On the "Fast" notch	18·5 km/h
Method of notching	mechanical

The two self-ventilated three-phase induction motors are each connected through gearing to a driving pinion. By changing gear mechanically it is possible to obtain two speed notches. The "Fast" notch is employed on slight slopes up to 9·5 %. For steeper slopes the "Slow" notch is used.

For braking in the super-synchronous region the traction motors act as asynchronous generators excited from the contact wire. In order to have an electric brake independent of the contact wire, in addition to the regenerative brake, one of the motors is equipped with a d.c. generator excited from a battery, which can excite the stators of the traction motors with d.c. when braking. The motors then act as synchronous generators on the rotor resistors. Both systems of electric braking can be used when travelling downhill, but the regenerative brake is given preference on account of its ability to recover power.

The rotor resistors can be varied in 12 stages and are dimensioned for continuous loading. It is thus possible to run downhill at low speed, as required for driving the rotary snow-plough. With the d.c. rheostatic brake the speed can be steplessly reduced to about 4 km/h on the downhill run. The fan motor for cooling the resistors can be supplied from the contact wire or, with d.c. braking, from the rotors of the traction motors, thus rendering the electric brake completely independent of the contact wire.

For mechanical braking the locomotives are equipped with a manually operated brake which acts on the two driving pinions and a gear brake which acts on the gearing between the traction motors and the pinions. The latter brake is automatically applied by a loaded spring if the permissible speed on the 25 % downgrade is exceeded. This brake can be applied from the locomotive or from the train by pulling the emergency lever. The train can be stopped and held at any point on the line with these brakes, even when fully loaded.

The locomotives can be run off 40 or 50 c/s. A few simple changes in connections will allow the equipment to be adapted to the future voltage change from 650 to 1125 V.

The converted locomotives will therefore be able to render several more years valuable service and assist the new motor-coaches to cope with the peak loads on the Jungfrau Railway.

(KME) Ž. FILIPOVIĆ

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AUTOMATIC CONTROL OF AERIAL ROPEWAYS AND FUNICULARS

625.92-52

Just as automation in factories, when properly applied, can greatly improve the quality and, above all the uniformity of the product, besides bringing economic advantages, the automatic control of aerial ropeways and funiculars can help to simplify the duties of the operating staff, allows the traffic schedule to be executed more uniformly and full advantage taken of the capabilities of the installation. The present article describes the limits of automatic control for passenger ropeways and explains the methods adopted by Brown Boveri.

ALTHOUGH the present article is devoted mainly to aerial ropeways, certain remarks are equally applicable to funiculars. Unless either of these is specifically mentioned the general term "ropeway" may be taken as a name covering both. Ropeways may be considered fully automatic when, in addition to the normal haulage duties, such tasks as taking the money, guiding the passengers and dosing them to the cars are performed automatically by means of automatic barriers or scales which only allow the permitted number or total weight of passengers through, assisted by slot-machines for small change, automatic door shutters, and so on. Such automatic ropeways have occasionally been built. They rely on a simple, as nearly uniform as possible tariff system according to weight and duties. The criterion for the time of departure may be given either by the clock time, or the weight aboard the car, or a combination of the two. The most economical method of operation is running to a publicly displayed time-table. At peak periods this system is discarded until such time as the demand exceeds the available capacity. This information is obtained from a "Cabin full" signal and the signal from a counter giving the number of persons in the waiting-room. If, on the other hand, there are no passengers waiting when a scheduled journey is due to start, that trip is not made, because neither of the above signals has been received. Complete automation in this manner, while permitting a marked reduction in the number of staff, nevertheless demands permanent attention and supervision by well trained specialists.

According to the statistics, the staff costs for a ropeway without automatic control amount to about 83% of the overall outlay. This fact, and the shortage of suitable personnel explain the growing importance of automatic control for ropeways.

The extent to which automatic control can and may be permitted to be adopted is primarily a question of personal opinion, but it depends also to a large degree on the significance, the location and the operating conditions of the ropeway. Whereas there are no serious objections which can be levelled at the automatic control of the drive, spreading to external service involves the user and sometimes the reliability too. Thus, for example, full automatic control of a funicular carrying passenger and goods traffic, with intermediate request stops, would be quite out of the question. Apart from purely operational considerations, the track of a funicular is particularly exposed to external influences, such as snow and ice, landslides, defective cable rollers, etc., which cannot possibly be properly detected by any automatic system and which therefore necessitate permanent accompaniment of the car. The only automatic installations of this kind are all short lines of low capacity. For the aerial ropeways employed for tourist and winter sports traffic in the mountains, the main objections to fully automatic control are of a psychological nature. The fact that a "local" is in charge greatly adds to the confidence of passengers who may be strangers to the mountains, and this factor must not be overlooked.

Looking back on the evolution of transport on the whole, the interesting discovery may be made that in no branch did automatic control come on the scene as early as it did with passenger ropeways.

This was doubtless favoured by the fact that the drive is stationary and, by nature, operation is according to a set unchanging winding diagram. Each trip commences with the input of the start command to the control equipment and finishes with the application of the service brake at the terminus. Between these come the phases: starting the converter set, checking the readiness for starting, closing the contactor for the particular direction of travel, starting and releasing the service brake, motoring at constant speed, retardation to the entry speed, checking this speed and, if necessary, reduction to the crawling speed, retardation to standstill and, finally, the application of the service brake. If calls have to be made at intermediate stations or certain sections have to be covered at reduced speed, additional retardation and acceleration phases may be included. During the entire sequence the load on the machine, the track and the speed must be continually supervised and the installation stopped if conditions exceed permitted limits. Exact adherence to the set programme is important for the maintenance of the guaranteed carrying capacity and may be considered a hall-mark of the automatic system.

One of the first ropeways equipped with automatic control from the car was the Harissenbucht–Fürigen ropeway on Lake Lucerne, which was taken into service in 1924. The whole of the electrical equipment for this was supplied by Brown Boveri [1].[1] For this ropeway, which is still in service, unchanged after all these years, a flywheel was fitted to the 16-kW slip-ring motor to compensate for different loading of the car. The motor is run up to its rated speed, corresponding to a travelling speed of 1·6 m/s, by a master controller operated by a servo-motor, with relays to effect the change in direction. By compensating for the varying loading conditions, the car can be braked to standstill at a constant point, merely by the service brake.

In 1931 there followed the considerably larger Davos–Parsenn funicular railway. For reasons of operational economy it was stipulated that this railway had to be controlled by a single machinist in the middle station at Höhenweg, where the drive of the lower section is located. This necessitated remote control of the second section up to the Weissfluhjoch, for which the cars had to be stopped at the termini as nearly as possible in the same position every time, even under extreme loading conditions. From economical considerations it was impossible to provide a flywheel to compensate for different loads in view of the driving power of 136 kW. Owing to the dependence of the speed characteristic on the load on the three-phase slip-ring motor, control of which was by the then conventional method with resistors in the rotor circuit, the stipulation regarding stopping at a constant point was extremely difficult to fulfil. Brown Boveri solved this problem by introducing, for the first time, two stages for the entry speed, with two motors [2]. When the car approached the terminus, the main motor was switched off and the brakes applied. At about $^1/_3$ of the normal speed the brakes were released and the car driven at crawling speed by the auxiliary motor until it was immediately before the final stopping point, where the brakes were applied once more. The final braking process from a speed of about 1·3 m/s, initiated by a dog on the track, enabled the car to be stopped with the desired accuracy.

As a consequence, the previously mentioned control system was progressively extended, in order to improve the accuracy of stopping, to make stopping more smooth by adapting the braking force to the different load conditions, and to reduce the strain and wear on the mechanical brakes. This led to a drive with a d.c. braking generator coupled to the winch motor, which brakes the car to the entry speed at the end of the trip. The energy liberated in the first braking phase is converted into electrical energy by the braking generator and dissipated in a resistor. The winch motor and the braking generator are controlled by a cam-type master controller actuated by a servo-motor in conjunction with the associated bank of resistors. Transmission of the signals from the car was by means of a contact pole touching a signal wire running alongside the track. With this drive system devised by Brown Boveri the Unterwasser–Iltios funicular was equipped in 1933 [3]. The same system was used again when the second section of the Davos–Parsenn funicular was converted to double the capacity in 1937, and for the conversion of the Gurten funicular in Berne in 1944.

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[1] The figures in square brackets refer to the bibliography at the end of the article.

The considerable growth in tourist and winter-sports traffic since 1945 has also brought new opportunities for the development of aerial ropeways. In addition to the increasingly popular circulating systems, such as chair-lifts, cabin lifts and ski hoists, a large number of high-capacity shuttle-service ropeways were also installed [4]. Though no new funiculars have been built, a considerable proportion of the existing ones have been adapted to the growing demand by increasing the speed, introduction of four-axle coaches with high capacities, and equipment with remote control [5]. Parallel to this development in the direction of increased load-carrying capacity, the demands for greater comfort, economy and reliability have also grown. Whereas it used to be customary for the whole route to be covered at a constant, relatively low speed and for the car to be braked mechanically from the reduced entry speed, this system is no longer practicable with modern installations having twice the speed and considerably higher load torques. Moreover, track or climatic conditions often necessitate adaptability at any time, i.e. temporary reduction in speed. On the other hand, the accurate adherence to the set time-table, in order to achieve maximum economy, demands acceleration and retardation independent of the load. These must be such that the passenger does not find them uncomfortable and the admissible motor current is not exceeded. Except for certain special cases, the cars should be braked electrically to a standstill, thereby avoiding jerking and, at the same time, reducing the wear on the brakes. The service brake is only intended for emergency stops and for securing the car when it has stopped.

The above conditions make safe control of the acceleration and retardation processes, and stepless control of the torque during starting and braking essential at all times. It must also be possible for the speed to be variable by remote control anywhere in the range. Obviously this cannot be fulfilled by a control system in which an input value is varied in order to influence a definite output value. The now increased demands with regard to accuracy and speed of control necessitate the use of closed-loop control. The motor speed has to be measured and the input signal continuously varied so that the output conforms to the preset desired value (Fig. 1).

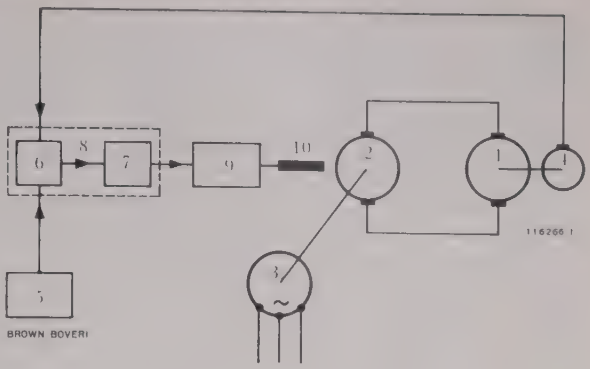

Fig. 1. – Speed control circuit of a Ward-Leonard motor driving a ropeway

1 = Winch motor
2 = Ward-Leonard generator
3 = Induction motor
4 = Actual-value unit
5 = Desired-value unit
6 = Comparison
7 = Pre-amplifier
8 = Regulator
9 = Power amplifier
10 = Generator field

For such variable-speed drives an ideal system is the d.c. motor with the well-known Ward-Leonard circuit. By means of quite a modest number of control elements it allows the speed to be varied steplessly down to standstill, regardless of the load, braking to a dead stop with regeneration of power, which can be returned to the supply system, and it also possesses a large overload capacity. These advantages, added to the mechanical robustness and reliability are so important that the lower efficiency, compared with three-phase machines, and the larger space occupied by a Ward-Leonard drive can be readily accepted.

In the years from 1947 to 1951 Brown Boveri have supplied automatic control for a number of funiculars driven by three-phase shunt commutator motors. A feature of this drive system is the small amount of space occupied and the good efficiency and power factor. However, its speed cannot be reduced steplessly to zero. Mainly on account of this disadvantage, this kind of motor has been superseded for high-powered drives by the Ward-Leonard system. But it is ideal for driving the circulating type of ropeways, i.e. chair and skilifts, requiring only one direction of rotation, and where

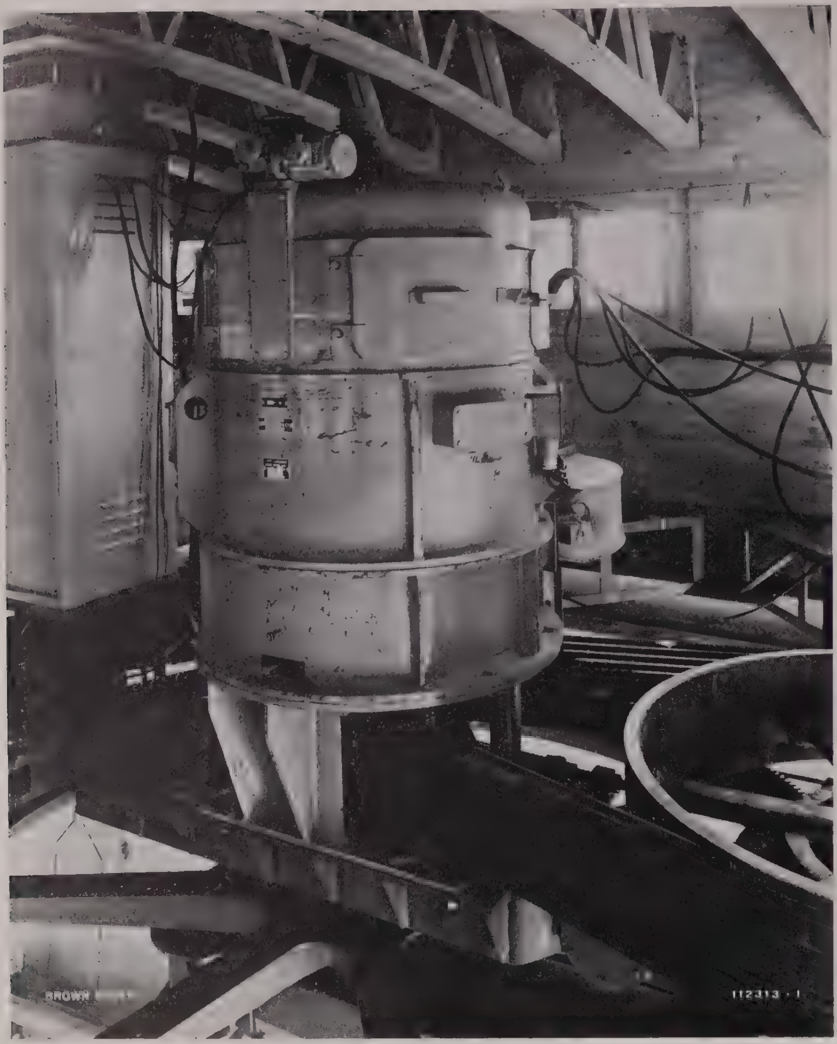

Fig. 2. – Three-phase shunt commutator motor driving the ski-lift on Clavadeleralp, operated by the Bergbahnen Bräma-Büel AG, Davos (Switzerland)

a restricted variation in speed is required to match the different numbers of passengers.

With closed-loop control (as in Fig. 3) the speed of the motor is first converted into a proportional voltage by means of a flanged-on tacho-generator; this voltage is then continuously compared with a desired-value voltage. If the two are unequal, there is also a deviation in the output quantity, i.e. the speed. In the regulator the persistent small difference between actual and desired value is amplified and conveyed as correcting condition to the power amplifier, which in turn varies the excitation of the Ward-Leonard generator. To relieve the rolling-sector regulator, acting as preliminary amplifier, the rotating amplifier is usually supplied with a basic excitation via a potentiometer. The desired-value potentiometer and the basic-excitation potentiometer are displaced by a common servo-motor. By varying the speed at which the potentiometers are run up or down it is possible to adapt the acceleration and retardation, and hence the drive programme, to the specific requirements of every installation. Controlling the travelling speed by means of a rotary amplifier involves hardly any losses and has the advantage of requiring the smallest control elements which, from the current aspect, are very lightly loaded and consequently free from wear and reliable.

For aerial ropeways the power amplifier can be either a rotary machine or a magnetic amplifier. The latter are somewhat more expensive and sometimes difficult to adapt to the drive system. On the

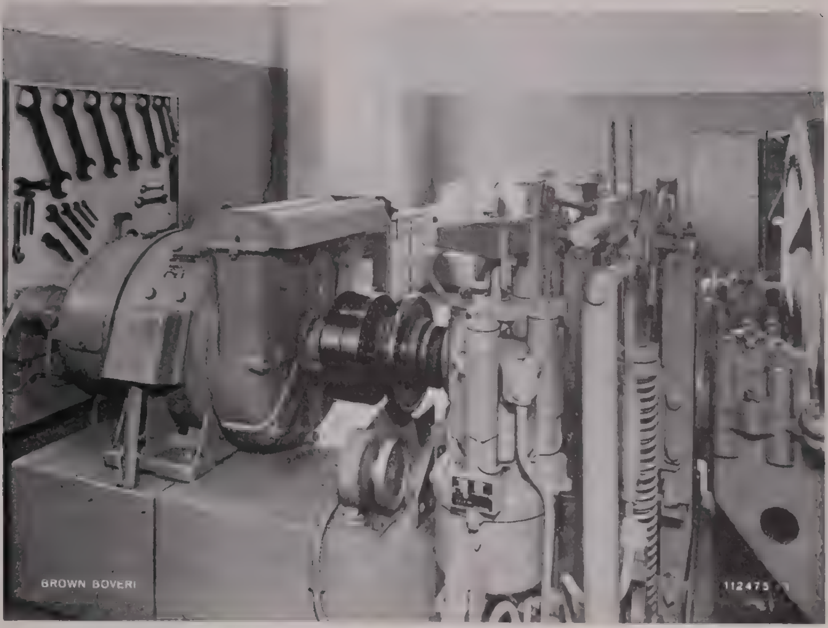

Fig. 3. – Ward-Leonard drive with tacho-generator fitted to the winch motor

At the rear is the main converter, in the foreground the electro-hydraulic thrustors for the service brakes.

other hand, magnetic amplifiers contain no parts exposed to wear, as is of course the case with the amplifier machine.

Fig. 4 shows the winding diagram of a funicular with an automatically controlled Ward-Leonard drive, recorded with a tachograph. The mean acceleration is only 0·18 m/s^2, which is sufficient to prevent the emergency brake being applied due to slack rope, even with an unloaded car coming down and maximum resistance to starting. The accuracy of stopping attains values which are otherwise only achieved by lifts.

The ability to maintain uniformly good accuracy when entering the termini, apart from depending on good speed control, relies on the braking process always being initiated from the same distance from the final stopping point. With funiculars this can be effected by dogs placed at the point in question on the track and actuating magnetic or electric switching devices. The problem is more difficult with aerial ropeways, where the contact elements have to be actuated by the position indicator for the cabin or by a synchro system. Errors due to rope slip on the driving sheave, rope stretch and change in diameter caused by wear of the sheave lining, are unavoidable and must be allowed for by a safety margin in the entry section. The latest development, employing radioactive isotopes incorporated in the rope and a switch operated by gamma rays as receiver, has greatly improved the accuracy of entry into the station.

Although in modern aerial ropeways the brakes are no longer applied to bring the cabin to a stop and are only used for holding when it has stopped, or in an emergency, it is still most important to correctly dimension the braking force applied. With maximum downgoing and minimum upgoing load the entire ropeway must be brought to a standstill within the maximum admissible braking distance. The same braking force, with the opposite loading conditions, would give rise to retardation values which were inadmissible from the material point of view, as well as for the passengers. Therefore, to prevent unduly abrupt braking, it is convenient to graduate the braking force in proportion to the load. This is effected by employing a pair of spring-operated brakes actuated by electro-hydraulic thrustors. This graduation can be extended by a third or fourth stage, by supplementing each of these braking devices with an extra weight to be lifted separately. The thrustors and the extra weights are automatically controlled by relays in function of the momentary load. Graduation may be in terms of time or speed. At any rate the full braking force must be effective at standstill so that, with full rising load and with this cabin on the steepest section, the system is prevented from slipping.

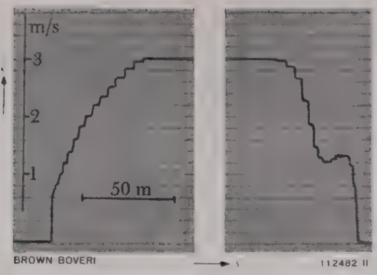

Fig. 4. – Travel diagram of an automatically controlled funicular with Ward-Leonard drive

In addition to its service brake, every ropeway also has a safety brake acting on the sheave, which is automatically applied if the speed exceeds the rated value by 15%. When this brake is applied, the drive must be switched off and the service brake prevented from being applied until the cabin has been brought to a standstill.

The systems of speed and braking control described above are supplemented by a series of supervisory elements. These keep a continuous check on the loading of the machines and the various control circuits, on the correct functioning of the brakes, the permissible speeds for travelling on the various sections, the position indicators, and so on. The tripping contacts of the supervisory elements are combined in a safety loop and, in the event of a breakdown, bring the ropeway to a standstill by tripping the interlocking relay, or they prevent it from being started. From safety considerations, the position indicator of automatic ropeways is usually augmented by a synchro system and a second interlocking relay, which check one another and stop the ropeway if it deviates from the set speed.

Automatic control of ropeways would never have been able to attain the importance which is attached to it today if it had not been for the simultaneous development of remote-control techniques. The signalling systems, which to begin with were only designed to transmit the directional commands

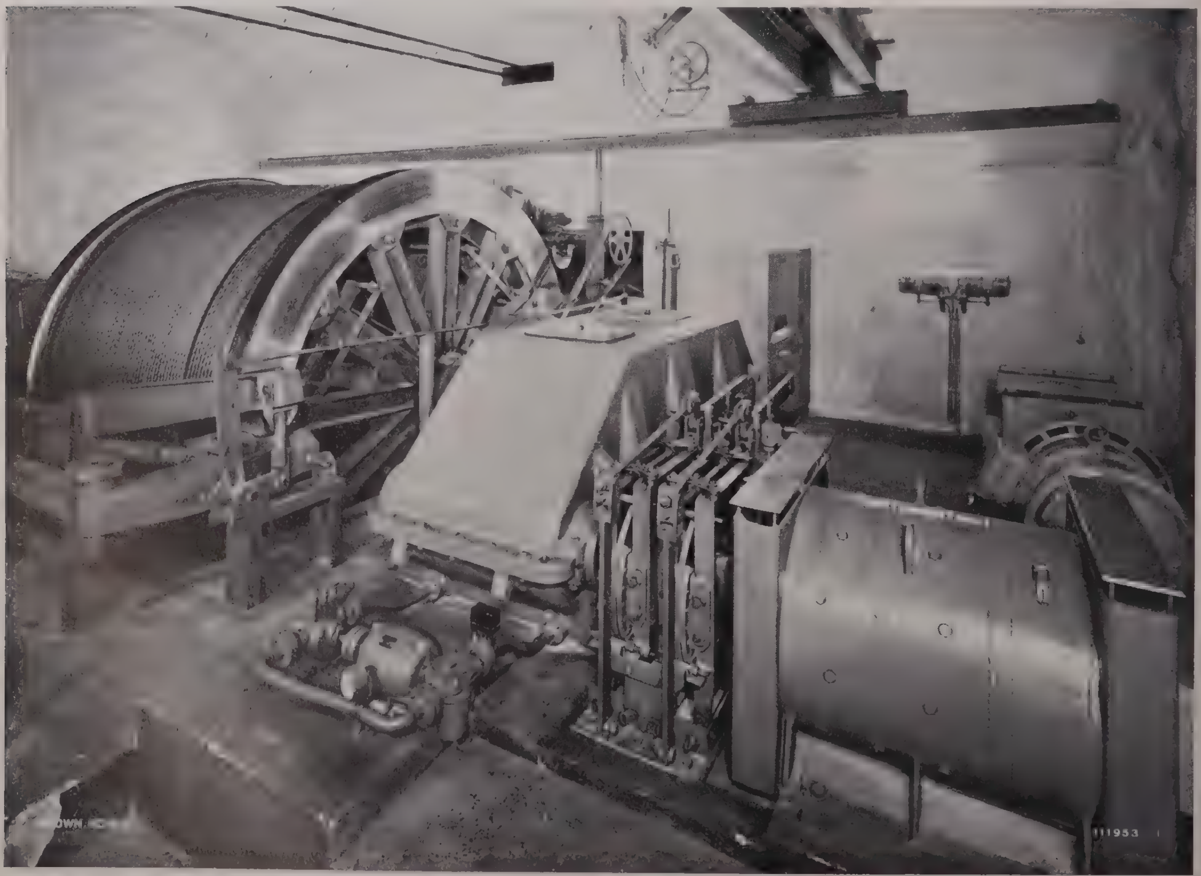

Fig. 5. – One unit of the 1200-hp twin drive of the 18-t aerial ropeway for the Linth-Limmern power scheme, Switzerland

"Up" and "Down" and the command to stop, have been extended and improved until, nowadays, it is possible to perform any operation from the cabin or car. The system of d.c. impulse control which was most commonly used, until a few years ago, is gradually being replaced by audio-frequency control with transistors. In this way it has largely proved possible to eliminate the sensitivity of d.c. control with respect to the variation of the contact resistance of the sliding contact on the cabin and to the insulation values of the rope, which can be extremely disturbing with aerial ropeways. The first transistorized system of a.f. control was installed by Brown Boveri in 1957 on the combined passenger and goods ropeway of the Biasca power scheme of the Blenio Power Co., in Switzerland. Since its installation this system has rendered excellent service.

The remote control for the 5-t aerial ropeway of the Linth–Limmern power scheme was designed according to the same principle; the parallel 18-t ropeway (Fig. 5), which will be dismantled when building work at the power station is ended, also has an automatic drive (rated 1200 hp), but this is equipped with push-button control from a control desk.

The reliability of the Brown Boveri a.f. control system has been improved in the meantime by introduction of the frequency-shift system, which prevents undesired control commands from being imparted as a result of atmospheric interference. With this system signals from several wavebands are continuously transmitted over the rope to the receiving station and a control command imparted by shifting the frequency of one or more signals, which causes a relay to pick up in the receiver and convey the appropriate command to the drive. The Brown Boveri a.f. control system employing the frequency-shift principle will be applied for the first time on the passenger aerial ropeway Airolo-Sasso della Boggia, due to commence service towards the end of 1960.

(KME) O. Manz

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BRIEF BUT INTERESTING

New 330-hp Diesel-Electric Industrial Shunting Locomotives

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This article describes a newly developed diesel-electric locomotive with a 330-hp engine, intended for shunting duties in factory areas. This locomotive extends the series described in an earlier article in this journal, having two similar units rated 100 and 200 hp.

The nature of the duties imposed on traction vehicles by shunting in a works of area is generally quite different to that experienced in main-line traffic. In most cases the track is also used by road vehicles and pedestrians too; doors and passages give directly on to the railway track. Therefore a prime requirement when a works locomotive is being designed is good visibility and easy control, so that the driver can devote his full attention to the track before him. Paying full attention to these requirements, Brown Boveri had already developed two types of locomotives for such duties, with ratings of 100 and 200 hp.[1] The gradients and sharp bends frequently encountered in factory areas, however, proved the necessity for a more powerful type in many cases. This Company, in collaboration with the Swiss Industry Co., Neuhausen (SIG), and Messrs. Adolph Saurer, Arbon, who provided the mechanical

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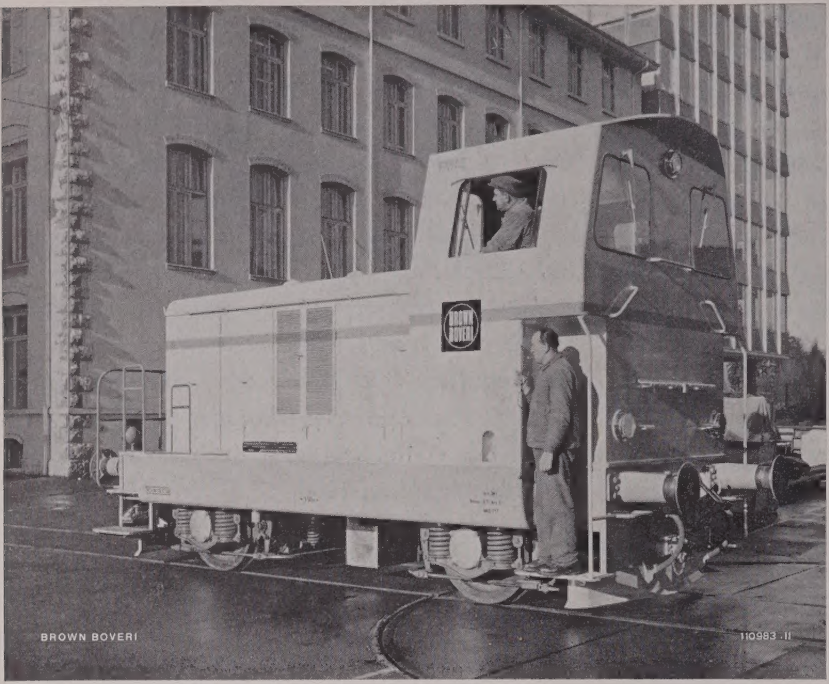
[1] E. M. Klingelfuss: Diesel-Electric Industrial Locomotives. Brown Boveri Rev. 1958, Vol. 45, No. 6, p. 279–92.



330-hp diesel-electric shunting locomotive

This type of traction vehicle pays particular attention to the severe requirements of industrial shunting duties. From his raised cab the driver has excellent visibility, while the recessed running board affords protection for the shunter.

equipment and diesel engine, respectively, have therefore brought out a model of this size, having the following characteristic data:

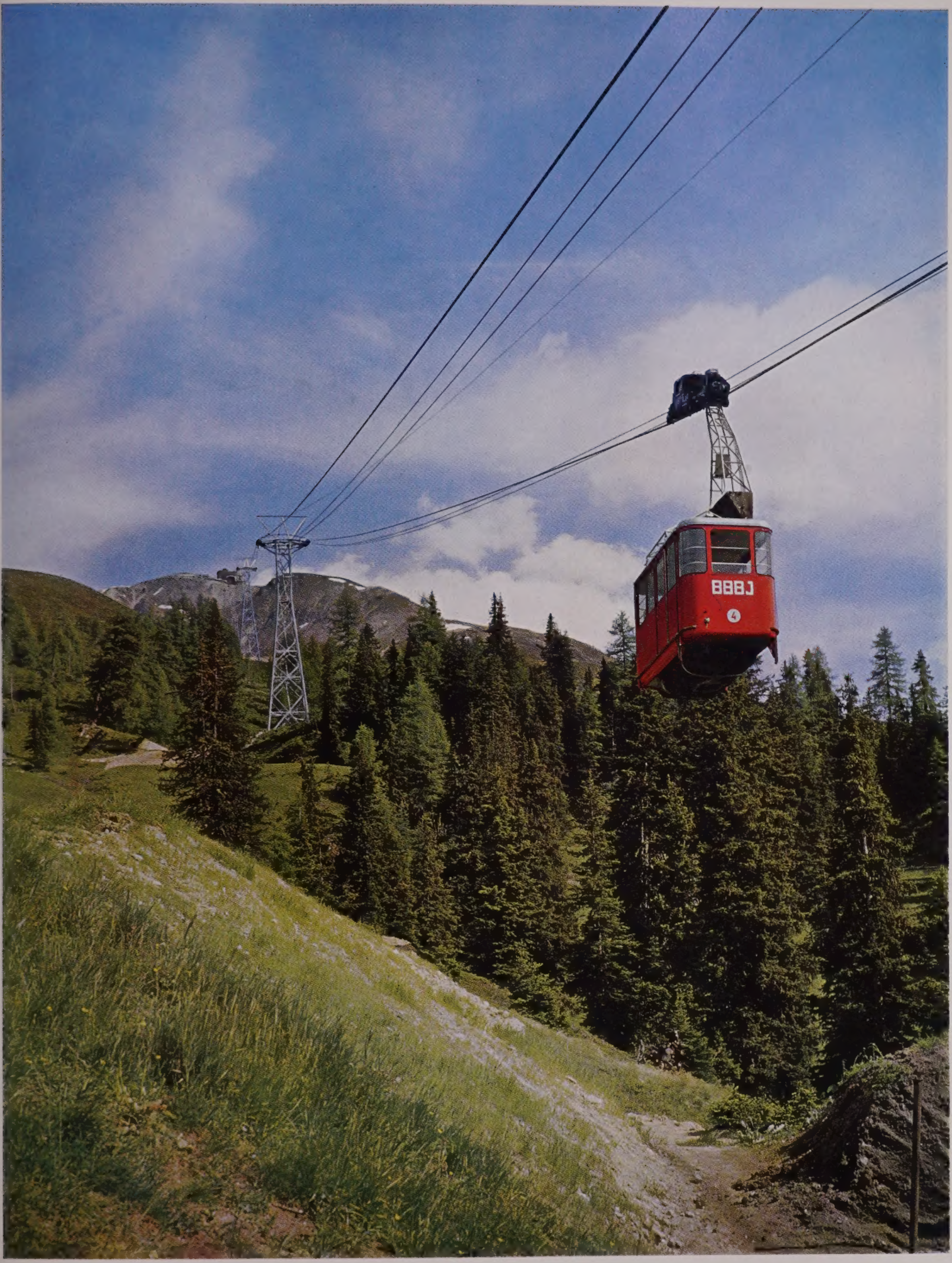
Power	330 hp
Gauge	1·435 m
Tare weight	39·5 t
Axle arrangement	B_0
Top speed	55 km/h
Tractive effort at start	11·7 t
Tractive effort at one-hour rated output of electrical equipment	5·1 t
Corresponding speed	12 km/h
Max. trailing load on flat	1300 t
Normal trailing load on flat	1000 t
Brakes	Pneumatic combined with rheostatic
Number of cylinders of diesel engine	6
Engine output (one-hour)	330 hp
Engine speed	1500 rev/min

A new feature of this locomotive is a rheostatic brake which, as a function of the current, overrides the pneumatic brake in such a manner that, with decreasing braking current, corresponding to decreasing speed, the pressure in the braking cylinder is continuously increased. This allows full advantage to be taken of the rheostatic braking system at any time. In addition, the braking current set on a controller is kept constant by a quick-acting regulator.

In order to utilize the power of the diesel engine as fully as possible, a servo field regulator system was incorporated for control. With normal injector pumps, combined with a speed governor, the adjustment forces available are so small that the well-known Brown Boveri servo field regulator cannot be actuated. Consequently a specially adapted electroservo field regulator was developed to suit these conditions.

The expedient and attractive design of the locomotive together with its performance, have already attracted attention and resulted in a number of orders being placed.

(KME) E. M. KLINGELFUSS



View of the Ischalp–Jakobshorn aerial ropeway, Davos, Switzerland

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